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Selection of the Next Generation of Air Traffic Control Specialists: Aptitude Requirements for the Air Traffic Control Tower Cab in 2018

Dana Broach
Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

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16. Abstract

The Federal Aviation Administration (FAA) faces two significant organizational challenges in the 21st century: (1) transformation of the current NAS into the Next Generation Air Transportation System ("NextGen"); and (2) recruitment, selection, and training the next generation of air traffic control specialists (ATCSs or air traffic controllers). What aptitudes should be assessed in the selection of future air traffic controllers? This report, the first of three, focuses on the aptitudes required in the air traffic control tower cab. First, the aptitude profile currently required at the time of hire into the ATCS occupation is described based on Nickels, Bobko, Blair, Sands, & Tartak (1995). Second, mid-term (2018) changes in the tower cab are described. Change drivers include increased traffic and the introduction of five decision support tools (DSTs): 1) Airport Configuration; 2) Departure Routing; 3) Runway Assignment; 4) Scheduling and Sequencing; and 5) Taxi Routing (with Conformance Monitoring). Third, the impact of these DSTs on tower cab operational activities, sub-activities, and tasks was assessed. Overall, the activities, sub-activities, and tasks of the controllers in the Ground Control and Local Control positions in the cab will not change with the introduction of these DSTs and associated displays. However, the way the work is performed will change at the keystroke or interface level. Fourth, the impact of the DSTs on aptitudes required of controllers is evaluated. The importance of the following aptitudes will increase in the mid-term: *Scanning*, across both auditory and visual sources, *Perceptual Speed and Accuracy*, *Translating Information*, *Chunking*, *Interpreting Information*, *Sustained Attention*, *Recall from Interruption*, *Situational Awareness*, *Long-Term Memory*, *Problem Identification*, *Prioritization*, *Time-Sharing*, *Information Processing Flexibility*, and *Task Closure/Thoroughness*. Two new aptitude requirements were identified: Dispositional Trust *in Automation*; and *Computer-Human Interface (CHI) Navigation.* Gaps in current aptitude testing are identified, and recommendations presented for test development and validation to close the gap.

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CONTENTS

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GLOSSARY

ACARS ---------- Aircraft Communications Addressing and Reporting System
AMS ------------- FAA Acquisition Management System
ARTCC --------- Air Route Traffic Control Center
ATCS ------------ Air Traffic Control Specialist
ATCT------------ Air Traffic Control Tower
AT-SAT ---------- Air Traffic Selection & Training Test (ATCS aptitude test battery)
CHI -------------- Computer-Human Interface (also Computer-Human Interaction)
CRT-------------- Cathode Ray Tube
DataComm ----- Data Communications
DST-------------- Decision Support Tool
EA---------------- Enterprise Architecture
FAA -------------- Federal Aviation Administration
FD/CD ---------- Flight Data/Clearance Delivery
GC --------------- Ground Control
IDRP ------------ Integrated Departure Route Planning
LC---------------- Local Control
LCD ------------- Liquid Crystal Display
PATCO---------- Professional Air Traffic Controller Organization
PDC ------------- Pre-Departure Clearance
RC---------------- Ramp Control
SID--------------- Standard Instrument Departure
TFDM----------- Tower Flight Data Manager
TDLS ------------ Terminal Data Link System
TFM ------------- Traffic Flow Management
TM--------------- Traffic Manager
TRACON------- Terminal Radar Approach Control
TS ---------------- Tower Supervisor
VHF ------------- Very-High Frequency
VDL ------------- VHF Data Link
UHF ------------- Ultra-High Frequency

EXECUTIVE SUMMARY

Problem

The Federal Aviation Administration (FAA) faces two significant organizational challenges in the 21st century: (1) transformation of the current National Airspace System (NAS) into the Next Generation Air Transportation System ("NextGen"); and (2) recruitment, selection, and training the next generation of air traffic control specialists (ATCSs or air traffic controllers). What aptitudes should be assessed in the selection of future air traffic controllers?

Aptitudes in personnel selection refer to the innate and learned abilities and other personal characteristics required of a person at the time of hire and for which the employer (the FAA) provides no specific training or development. Air traffic control (ATC) knowledge and skills are learned after hire through formal and on-the-job training. Short-term memory, perceptual speed, and emotional stability are examples of aptitudes. Aircraft weight classes, wake vortex separation procedures, and amending flight routes are examples of ATC-specific knowledge and skills.

This report focuses on the aptitudes required to work in the ATC tower cab (ATCT or "tower cab") environment. The analysis assumes that selection will continue to be based on aptitude, not demonstrated ATC-specific knowledge and skill.

The analysis is straightforward: Compare current aptitude to future aptitude requirements. First, the current work of tower cab controllers is described. Second, the current aptitude profile is reviewed. Third, the future work of tower cab controllers circa 2018 is described, based on a review of available information. Fourth, future aptitude requirements are deduced based on the description of work in the mid-term tower cab. Fifth, the current aptitude profile is compared to the future aptitude profile. The report closes with specification of the abilities to be assessed in the future and recommendations for test development and validation.

Current Work

The current work of controllers is organized around four operational positions in the tower cab: Flight Data, Clearance Delivery, Ground Control, and Local Control. At present, the cab controllers have little automation support in the form of decision support tools (DSTs). The primary mode of communication with aircraft is VHF radio. Departure clearances are delivered electronically at large airports equipped with the Tower Data Link System (TDLS). Controllers rely upon the out-the-window view of operations, flight strips (or their functional equivalent, depending on local facility practices and policies), and the surface and airspace radar displays to determine the position and identification of aircraft and to formulate control instructions and other communications. Control is very tactical on a short time horizon and is based on the "First Come, First Served" paradigm.

Current Aptitudes

The aptitudes currently required can be organized, for discussion purposes, around an input-process-output model.

Input to the controller is through *Active Listening* and visual *Scanning*, with *Perceptual Speed and Accuracy* as the limiting factor.

From a process view, what is seen and heard is entered into *Short-Term Memory* and used to construct a model of the current and future state of operations. The abilities called upon include *Situtational Awareness*, *Visualization*, *Dynamic Visual-Spatial* ability, and *Summarizing Information*. Any current and anticipated problems are solved through *Problem Identification*, *Prioritization*, *Rule Application*, and (logical) *Reasoning*. The dynamic comprehension of the current and future state of operations and problem solving require *Sustained Attention* and *Concentration* from the controllers. Working traffic draws upon their ability to *Think Ahead*, *Plan*, and *Project (Projection)* from the current to the near-term future. Controllers must divide their attention and perform multiple tasks (*Time-Sharing*). Performance of the job requires constant *Self-Awareness*, *Self-Monitoring/Evaluation*, and *Information Processing Flexibility*. Controllers must have *Self-Confidence*, be willing to *Take Charge* of a situation with *Tolerance for High-Intensity Work Situations*, and do so by *Working Cooperatively* while maintaining their emotional *Stability/Adjustment*.

Controller outputs are control actions delivered primarily as voice instructions to pilots. Some keyboarding and writing is required.

Future Work

In the mid-term (circa 2018), DSTs will be introduced in the cabs at the 30 largest and busiest airports such as Dallas/Fort Worth (DFW) and Atlanta (ATL). Five DST capabilities are envisioned for the tower cab at these complex facilities: *Airport Configuration*, *Departure Routing*, *Runway Assignment*, *Scheduling and Sequencing*, and *Taxi Routing* (with *Conformance Monitoring*). The DSTs will generate recommendations for control actions. Some instructions will be delivered electronically to the aircraft view Data Communications (DataComm) Segment 1, building on Tower Data Link System (TDLS); however, time- and safety-critical messages will still be delivered by voice in the mid-term (Wargo & D'Arcy,

2011). The goals for the tower cab DSTs include reduced waiting and taxi times, greater utilization of resources, increased throughput (especially in bad weather) and decreased environmental impact, through more "strategic "management of the traffic on the surface and in the immediate airspace. The computational algorithms underlying the five DSTs are the subject of intensive research, engineering, and development. Assuming that stable and robust solutions will be delivered, the Runway Assignment, Scheduling and Sequencing, and Taxi Routing (with Conformance Monitoring) DSTs are likely to change the "how" rather than the "what" controllers do working traffic in the tower cab. The concepts of operation and use for each DST require controllers to accept, reject, or modify the recommended control action, such as a sequence for departures and runway assignments via unspecified (as yet) computer-human interfaces (CHIs). This has two primary implications. First, controllers will be required to interact with the DSTs and associated displays. Second, controllers will evaluate the proposed (computed) solution and remain responsible for the safety and efficiency of surface operations.

Future Aptitudes

Overall, the introduction of surface-oriented DSTs under the NextGen umbrella and increased traffic will result in a shift in emphasis on the aptitudes required for successful performance in the tower cab of 2018. Some aptitudes that are important now will become more important in the future, and a few will become less important in the future. This evolutionary shift in emphasis resulting from NextGen is summarized as follows in the context of an "input-process-output" framework for human aptitudes.

First, in terms of aptitudes relating to acquiring information ("input"), Scanning (of visual sources), Perceptual Speed and Accuracy, Translating Information, Chunking, and Interpreting Information will increase in importance to successful performance in the tower cab. This is especially true for towers at the 30 largest airports that are most likely to receive surface-oriented DSTs in the mid-term. Second, from a "process" perspective, the importance of attention and memory aptitudes such as Sustained Attention, Recall from Interruption, Situational Awareness, and Long-Term Memory to successful job performance will increase in the mid-term. The increase in the importance of Sustained Attention and Recall from Interruption is driven by the projected increases in ATC operations. The increase in the importance of Situational Awareness and Long-Term Memory is coupled to the surface-oriented DSTs needed to handle the increase in traffic. Third, Problem Identification and Prioritization will become more complicated and more important in the mid-term, depending on the transparency and operational acceptability of the mid-term DST recommendations and the reliability of the systems. The importance of the aptitudes Time-Sharing, Information Processing Flexibility, and Task Closure/Thoroughness will increase with both traffic and the implementation of surface-oriented DSTs. Fourth, just two new aptitude requirements were identified with NextGen in the mid-term: Dispositional Trust in Automation and CHI Navigation. Finally, in terms of "output," the importance of the aptitude Manual Dexterity (in using a keyboard, mouse, touch screen, and/or numeric keypad) will depend on the actual CHI implementations but is likely to increase.

Aptitude Testing Gap Analysis

The current ATCS occupational aptitude test battery assesses many, but not all, of the aptitudes likely to be important to successful job performance in the mid-term tower cab of 2018. Three input-related aptitudes that will become more important (than they currently are) to job performance in the 2018 tower cab are not currently assessed in the pre-employment testing: *Translating Information*, *Chunking*, and *Interpreting Information*. Three process-related aptitudes that will be important to tower cab controller performance in 2018 are not explicitly assessed in the current test battery: *Sustained Attention*, *Long-term Memory*, and *Time-sharing*. *Dispositional Trust in Automation* is a new aptitude requirement associated with NextGen DSTs. The two output-related aptitudes likely to be important in 2018, *CHI Navigation* and *Manual Dexterity*, are not assessed in the current test battery.

Some of the aptitudes that will be important in the mid-term are assessed through multi-factorial tests, but explicit scores for those aptitudes are not computed. For example, while it is clear that applicants must prioritize their actions in both the Letter Factory Test and Air Traffic Scenarios Test, there are no scores explicitly representing *Prioritization*. Similarly, while applicants are required to perform multiple tasks such as tracking objects, considering the next actions to be taken simultaneously in those two dynamic, multi-factorial tests, the candidate's time-sharing capacity can only be inferred from the overall scores on the tests. No explicit score for *Time-sharing* as a psychological construct is derived from either test.

More subtle gaps between current ATCS aptitude testing and mid-term requirements exist. For example, the current test of *Scanning* is based on a 2-D radar display rather than an out-the-window search of a true 3-D visual scene for relevant information. It is not clear if scanning the two sources invokes the same fundamental ability. Another gap is the relative importance (weights) assigned to tests representing the aptitudes likely to be more or less important to successful job performance in the tower cab of 2018. Finally, aptitudes *Sustained Attention* and

Concentration are assessed by a questionnaire (e.g., self-reports of typical behavior). While assessment of traits such as *Self-awareness* and *Stability/Adjustment* are widely available for personnel selection, reliance on self-reports for attention-related aptitudes is problematic. Self-reports can be vulnerable to applicant impression management tactics and socially desirable response sets, particularly in high-stakes selection settings. Assessment of attention-based performance would be preferable.

Recommendations

To close these gaps in ATCS aptitude testing, the following actions are recommended.

First, adapt or develop and then validate tests for *Dispositional Trust in Automation*, *CHI Navigation*, and *Manual Dexterity*. These aptitudes are not currently assessed in pre-employment aptitude testing but will be important to job performance under NextGen.

Second, adapt or develop and then validate tests for the following aptitudes: *Translating Information*, *Chunking*, *Interpreting Information*, *Sustained Attention*, *Long-term Memory*, and *Time-sharing*. These aptitudes were identified as important in the baseline job analysis. They are likely to become more important to job performance in the mid-term tower cab than at present, particularly with the implementation of surface-oriented DSTs under the NextGen umbrella. These aptitudes are not currently assessed in pre-employment aptitude testing.

Third, derive scores from the multi-factorial tests, if possible, to represent the aptitudes *Prioritization* and *Time-sharing*. These aptitudes are likely to become even more important in the mid-term tower than they are now because of both NextGen and increased traffic. Alternatively, adapt or develop tests of these aptitudes. Validate the derived, adapted, or newly developed tests for these aptitudes against mid-term job performance measures for tower cab controllers.

Fourth, conduct multi-trait, multi-method analyses of *Scanning* of different sources of visual information such as a true 3-D out-the-window view versus 2-D representation of that view and 2-D radar display. Determine if different tests are required.

Fifth, review the relative weights for aptitudes assessed in the current occupational aptitude test battery in relation to their increased importance to the mid-term cab environment with surface DSTs. In other words, reflect the shift in emphasis or degree on the various aptitudes relevant to job performance in the mid-term towers of large airports in the weights assigned to scores representing relevant aptitudes. This recommendation includes determination of cut-scores to reflect minimum requirements, if justified.

Sixth, investigate alternative performance-based assessments of *Sustained Attention* and *Concentration* that do not rely upon transparent, self-report questionnaires of applicant "typical" behavior.

Finally, each of the recommended studies should be conducted in accordance with accepted guidelines, standards, principles, and practices for the development and validation of personnel selection tests. Specific attention and resources must be given to the development of meaningful, reliable, and valid measures of controller job performance in the tower cab of 2018 against which to validate future-oriented tests.

Selection of the Next Generation of Air Traffic Control Specialists: Aptitude Requirements for the Air Traffic Control Tower Cab in 2018

The Federal Aviation Administration faces two significant organizational challenges. The first is to transform the current National Airspace System (NAS) into the Next Generation Air Transportation System ("NextGen"). NextGen intends to shift the fundamental air traffic control paradigm from ground-based tactical control to satellite-based strategic management (FAA, 2010g). The transformation can be organized into three time periods: near-term (now through about 2015), mid-term (through about 2018), and far-term (through about 2025 and beyond). The second challenge is to recruit, select, and train the next generation of air traffic control specialists. The two challenges are intertwined: The evolution of NextGen will impact the knowledge, skills, abilities, and other personal characteristics required of controllers in the future, yet the characteristics of the workforce will influence the design of NextGen. This report is the first in a series that evaluates the impact of NextGen on the selection of the next generation of air traffic controllers.

Report Organization

This report is organized into five parts. First, the overall problem and setting are described. Second, the current work of controllers is described. This "as is" description includes the aptitude profile currently required to enter the controller workforce. Third, what the work of controllers might look like at a specific future time is described. This "to be" description includes the aptitude profile that might be required to enter the workforce. Fourth, the current and future aptitude profiles are compared in relation to current selection procedures to identify gaps. Finally, conclusions and recommendations are presented.

Problem and Setting

The air traffic control specialist (ATCS, "air traffic controller," or simply "controller") workforce is the single largest (>15,000 controllers and 1st-level supervisors as of FY2010; FAA, 2010d) and most publicly visible workforce in the FAA. It is also experiencing a unique generational change. The FAA hired a large cohort of controllers following the 1981 PATCO strike (see Broach, 1998). Most of the members of this "Post-Strike Generation" were under age 30 when hired. Now, that workforce is aging. In 1996, the average age of the Post-Strike Generation of controllers at field facilities was 37, and most (88%) were hired between August, 1981 and March, 1992 (Schroeder, Broach & Farmer, 1998). Now, in 2010, the average age of the Post-Strike Generation is 48, and they represent just 44% of the non-supervisory controller workforce assigned to field facilities. Most members of the Post-Strike Generation face mandatory retirement at age 56 by about 2018. The FAA projects hiring about 10,000 new controller trainees by 2018 to replace those losses; about 80% will successfully complete the arduous two to three year training program (FAA, 2010a; see Table 4.1, p. 27 and Figure 5.1, p. 37).

Hiring 10,000 new controllers is a significant organizational effort. Based on recent FAA experience in recruiting and selecting over 7,000 Next Generation controllers since 2002, the FAA can expect many applicants for each opening. The selection problem is complicated by the need to consider not just current aptitude requirements, but also aptitudes that are likely to be required by NextGen in the mid-term.

There is considerable speculation on what aptitudes will be required of Next Generation controllers. For example, the Congress directed the FAA to investigate "the attributes and aptitudes needed to function well in a highly automated air traffic control system and the development of appropriate testing methods for identifying individuals with those attributes and aptitudes" in the Aviation Safety Research Act of 1988 (Public Law 100-591 (November 3, 1988), codified at Title 49 United States Code section 44506(a) (3)). In 1995, Cole suggested that the ATC system of the future "…will require individuals with a different mix of abilities than what is needed today" (p. 47). A National Research Council panel came to a similar conclusion, suggesting that different abilities, or a different weighting of abilities, might be required under different future automation paradigms (Wickens, Mavor, & McGee, 1997). More recently, the FAA National Aviation Research Plan set out a requirement to "Develop selection procedures to transform the (controller) workforce into a new generation of service providers that can manage traffic flows in a highly automated system" by 2015 (p. 35). The assumption reflected in these and similar documents is that the aptitude profile required to work "in a highly automated system" will be at least qualitatively different than what is required to work in today's air traffic control system.

However, the available empirical data suggest that the aptitudes required to enter the occupation are more stable than assumed (Manning & Broach, 1992; Eißfeldt, 2009; Goeters, Maschke, & Eißfeldt, 2009). However,

it might be the case that some of the abilities on which controllers were selected in the past might not be justifiable in the future and that new ability constructs might become important. A systematic evaluation of the impact of NextGen on the aptitudes required to enter the controller occupation is needed.

In considering what to assess in selection, it is important to define what is meant by "knowledge, skills, abilities, and other personal characteristics" (KSAOs). For purposes of this strategic job analysis, "knowledge" and "skill" are defined explicitly as the ATC-specific information, procedures, and methods that the FAA teaches new controllers through formal instruction at the FAA Academy and on-the-job training at an ATC field facility. In contrast, "abilities" and "other personal characteristics" are used to specifically refer to innate and learned abilities and other personal characteristics required at the time of hire and for which the employer (the FAA) provides no explicit training or development. "Aptitude" is used throughout this report as a shorthand label for these innate and learned abilities and other personal characteristics. Aptitude in this usage encompasses cognitive attributes of a person such as working memory and logical reasoning, perceptual abilities such as color vision and hearing, and personality traits such as conscientiousness and emotional stability. Aptitude, as used in this report, also includes learned capabilities such as comprehension of spoken and written English, arithmetic, basic algebra (for example, computing time from speed and distance), and recognizing angles. These abilities are acquired through education and experience before a person is considered for employment by the FAA. The focus of the strategic job analysis is on the aptitudes required to enter the ATCS occupation, on the assumption that the selection policy of the FAA for controllers will continue to be based on aptitude, not on demonstrated ATC-specific knowledge and skill. ATC-specific knowledge and skills are explicitly excluded from this analysis.

The FAA must decide when to make changes to the ATCS selection procedures. A selection procedure is required to be grounded in the realities of the actual job, not in what might or might not be the work at some distant point in the future with some reasonable degree of certainty. On one hand (or time horizon), the vision of NextGen in 2025 is conceptual rather than concrete; to what degree that vision will be achieved is yet to be seen. Therefore, targeting aptitude requirements in the far-term is likely to be unrealistic – and indefensible within the current technical and legal framework for the development and validation of employee selection procedures. On the other hand, the FAA has invested substantial effort in defining what is termed the "mid-term" NextGen at about 2018. Sufficient information about specific technologies and procedures is available through formal concepts of operation and use, design descriptions, requirements documents, human-in-the-loop (HITL) simulations, and prototypes in demonstration and operational testing to deduce future aptitude requirements with some degree of confidence. Therefore, this analysis focuses on the mid-term NextGen at 2018.

Finally, to make the analysis tractable, each report in this series will analyze an operational working environment. The iconic ATC facility at an airport is the glass cab on top of the ATC tower. Controllers in the tower cab direct pilots to land and takeoff from the airport. They direct traffic on the runways, taxiways, and in the airspace around the airport out to about three to five miles. Tower cab controllers rely upon direct visual observation of aircraft operating on the airport surface and in the immediate airspace around the airport. Surface and airspace radar displays are available to the controllers at many (but not all) towers.

Once a departing aircraft is the air, it is handed off to a controller in the servicing Terminal Radar Approach Control (TRACON) facility. TRACONs are less well known to the public but are critical to the safety and efficiency of flight. TRACON controllers direct flights into and out of the airspace around an airport (or airports), generally out to about 50 miles and up to 10,000 feet in altitude. TRACON controllers rely upon radar to "see" the traffic. Some TRACONs are co-located with the tower. For example, the tower serving the Will Rogers International Airport (OKC) in Oklahoma City has both a cab on top of the tower and a TRACON at the base of the tower. Other TRACONs are stand-alone facilities, particularly those that serve metropolitan areas with multiple airports, such as the New York City area, Chicago, the Dallas-Fort Worth metroplex, Atlanta, and southern California (Los Angeles and San Diego). TRACON controllers hand off departing flights to controllers at a third facility type known as an air route traffic control center (ARTCC, "en route center," or simply "center"). Center controllers provide air traffic services to aircraft flying between airports, usually at higher altitudes. Like TRACON controllers, they rely upon radar to "see" air traffic. Multiple centers might handle a flight, depending on its route. An arrival is handled in reverse: center hands-off to the TRACON; TRACON hands off to the tower cab.

Given the diversity of the operating environments, focusing on one type of facility at a time makes the analytic problem more tractable. Thus, the work of controllers in the tower cab circa 2018 is analyzed in this report. Subsequent reports will analyze the work of controllers in the TRACON and ARTCC environments.

CURRENT TOWER CAB

Overview

When air traffic control is mentioned, the first thought is often of the control tower cab at an airport. Airports have long been recognized as a constraint on the capacity of the NAS (FAA, 2007; Feron et al., 1997; Gosling, 1993; Shaver, 2002). Airports constrain NAS capacity in several ways. First, there are limits to the number of aircraft that can physically be handled at any given moment on the airport surface. These limits include the number of gates for emplaning and deplaning passengers (and cargo), ramps (also called alleys), taxiways, and runways (Figure 1). For example, only so many airplanes can physically occupy a taxiway of a given length at a given point in time. Only one airplane at a time can occupy a gate, and there are only so many gates in a terminal.

Second, ATC procedures impose operational limits on airports. For example, controllers may require aircraft to wait at an intersection while other traffic proceeds through the intersection. A departing aircraft might have to line up and wait on the departure runway until an arrival has gone a specified distance down the runway or turned off. Smaller aircraft have to wait to take off behind "heavy" aircraft such as a Boeing 747, due to wake turbulence. Arrivals on closely-spaced parallel runways might have to be staggered by a specific distance.

Third, weather constrains airport capacity. Weather is a leading cause of delays. For example, aircraft that might be departing from other airports (say, from New York's LaGuardia (LGA) to Dallas-Fort Worth International (DFW)) one afternoon might be delayed on the ground due to a summer thunderstorm and high winds at DFW. Similarly, the planned departures out of DFW to LGA and other airports might also be delayed until the thunderstorm passes. After the thunderstorm, DFW might experience congestion until the backlog of flights is cleared.

Fourth, random (stochastic) events constrain capacity. While these events can be expected, their actual occurrence is unpredictable. Example stochastic events that constrain airport capacity are aircraft mechanical problems and holding for late-connecting passengers.

Finally, controller workload might also constrain capacity. For example, Balakrishna, Ganesan, and Sherry (2009) asserted that controllers "are often overwhelmed by the increase in the number of arrivals and departures during peak hours of operation" at major hub airports. The same assertion had been made 40 years earlier: Controllers became fatigued under peak loads and had difficulty in "retaining the picture" required to safely and efficiently direct arrivals to and departures from the airport (Luffsey & Wendell, 1969).

These five physical, operational, and psychological limits combine to constrain the flow of aircraft through an airport, particularly the major hubs for which there are overlapping "banks" or waves of departures and arrivals throughout the day (Glass, 1997; Idris et al., 1998).

One well-known and frequently experienced form of delay is in taxiing out to the departure runway. Indeed, the iconic image of aviation delay is a queue of outbound aircraft, lined up almost nose to tail, inching their way along a taxiway to the end of the departure runway. The aircraft engines spool up and down as the aircraft move forward in short spurts, burning fuel and releasing carbon

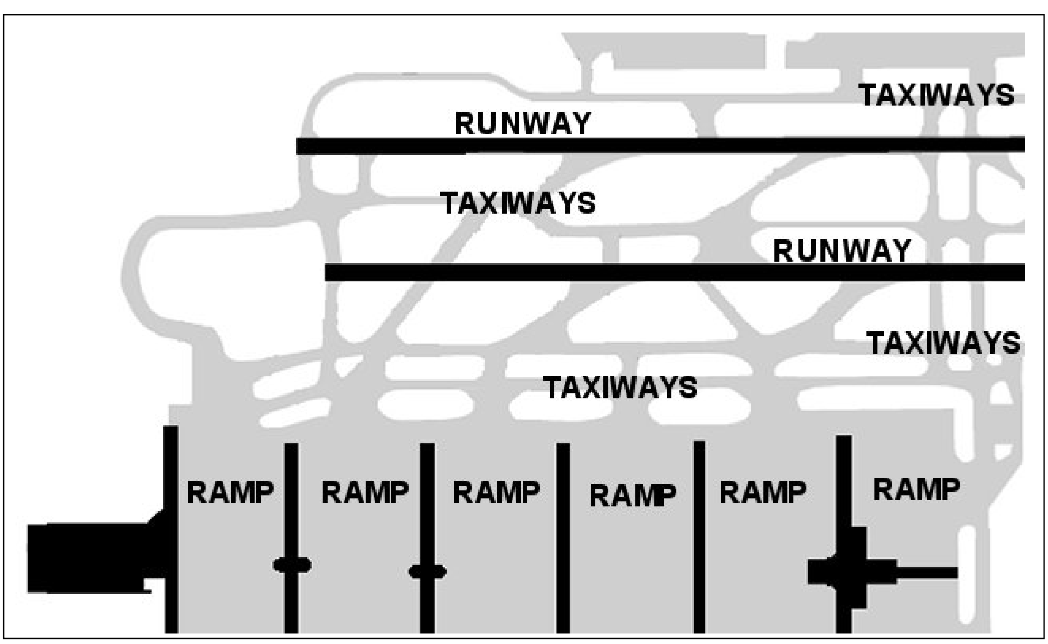

Figure 1: Example airport layout (from Atlanta Hartsfield (ATL)) illustrating ramps, taxiways, & runways

dioxide and other pollutants. The average taxi-out delay in minutes-per-flight is approximately twice that of airborne delay; the cost of taxi-out delay is about one-third greater than the cost of airborne delay (Atkins, Brinton & Walton, 2002). Reducing taxi-out and other delays on the airport surface, thereby increasing the efficiency of the airport, might have significant benefits to the operators and the public in the forms of greater operational predictability, scheduling, and reduced emissions. To that end the National Aeronautics and Space Administration (NASA) and the FAA have conducted significant research on methods for increasing airport efficiency and reducing delays.

One approach to reducing delays in airport surface operations provides tools for tower cab controllers to control departing and arriving aircraft on the airport surface and immediate airspace around the airport. The cab controllers perform a series of sequential control tasks for each departing and arriving aircraft. Depending on airport configuration, they instruct the pilot of departing aircraft when to push back from the gate, what taxi route to take to the departure runway, and when to take off (Anagnostakis, Clarke, Bohme, & Volckers, 2001). An arrival is handled in reverse; pilots are instructed on which runway to land, what exit to take from the runway, and what taxi route to take to the gate. Most of these instructions are issued by voice by controllers to pilots via Very High Frequency (VHF) radio (Gosling, 1993). The procedures used in managing departures and arrivals are largely "manual," that is, performed with little, if any, computer support. At large, hub airports such as DFW, ATL, Chicago's O'Hare (ORD), and Los Angeles International (LAX), these communication and control tasks impose a high workload on controllers and must be performed under significant time pressure. There is no time for errors.

Moreover, modern airports such as ORD have multiple terminals, a complex web of taxiways, and multiple parallel, diverging, and sometimes intersecting runways (Figure 2). Finding an "optimal" taxi route and runway assignment, in real time, that minimizes taxi-out time and meets other criteria for a given flight can be complex and difficult. Anagnostakis and Clarke (2002) argue that "given the complexity of the departure process and the site specific nature of departure operations, it is difficult for controllers to fully explore all the possible solutions within the relatively short time period in which decisions must be made" (p. 1). Controllers might rely upon established procedures and pre-planned taxi routes based on the configuration of the airport at a given time. However, those plans might not result in an optimal solution from the operator's view for a specific flight. A proposed solution is to provide automation aids or decision support tools (DSTs) to cab controllers to "help optimize and control the departure flow" to benefit both controllers and aircraft operators (Anagnostakis & Clarke, 2002, p. 1). The expectation is that DSTs will enable tower cab controllers to handle more aircraft with greater efficiency, less delay, increased safety, and less environmental impact.

This is not a new idea. For example, a system for computer-ordered arrivals spacing was tested in the mid- and late-1960s in a laboratory simulation and with live traffic at New York's John F. Kennedy International (JFK) airport, reportedly with some success (Cirino, 1986). Hurst described the Surface Traffic Control System (STRACS) as an automated ground control system. STRACS was intended to "… relieve the human Ground Controller in the Tower from much of the burdensome routine tasks associated with ground control" (1971, p. 15). The controller's role would be one of "instructing the computer and monitoring the complete system operation" (p. 15). The early 1980s brought the Terminal Air Traffic Control Automation (TATCA) as a component of the FAA's Advanced Automation System (AAS) program that was to modernize the NAS (Gosling, 1993). Yet nearly 30 years later, the tower controller's role and the tools available have not significantly changed. Control of the airport surface is still the least automated part of the ATC system, relying largely on controller "out-the-window" surveillance, voice radio, and controller judgment (Gosling), despite significant investments in research and engineering.

Tower ATC operations might change under NextGen in two ways. First, surface operations in NextGen will change from "a highly visual, tactical environment to a more strategic set of operations that are independent of visibility, better achieve operator and ANSP [air navigation service provider] efficiency objectives, and better integrate surface, airspace, and traffic flow decisionmaking" (Joint Program Development Office (JPDO), 2007, p. 2-5). The NextGen controller (re-titled as the "Air Navigation Service Provider," or ANSP[1]) will rely "more on automation to perform routine tasks, yielding ANSP productivity gains as controllers handle more traffic" at major airports and take "a more strategic view" (p. 2-27) of airport surface operations. Digital data communications between flight operators and the ANSP will be the norm, with voice radio used on exception and as a backup (p. 2-31). Second, air traffic control services at lower-volume airports might be provided remotely through a "Staffed NextGen Tower" (FAA, 2008a). Controllers will provide services from a "ground-level," possibly off-airport facility to one or more airports. The controllers "will be assisted by an integrated tower information display that presents weather, surveillance data and other essential information and [a] suite of decision support tools (DSTs)" (p. 1). An "alternative method" will be used in lieu of the out-the-window view from today's tower cab for "…various ATM functions

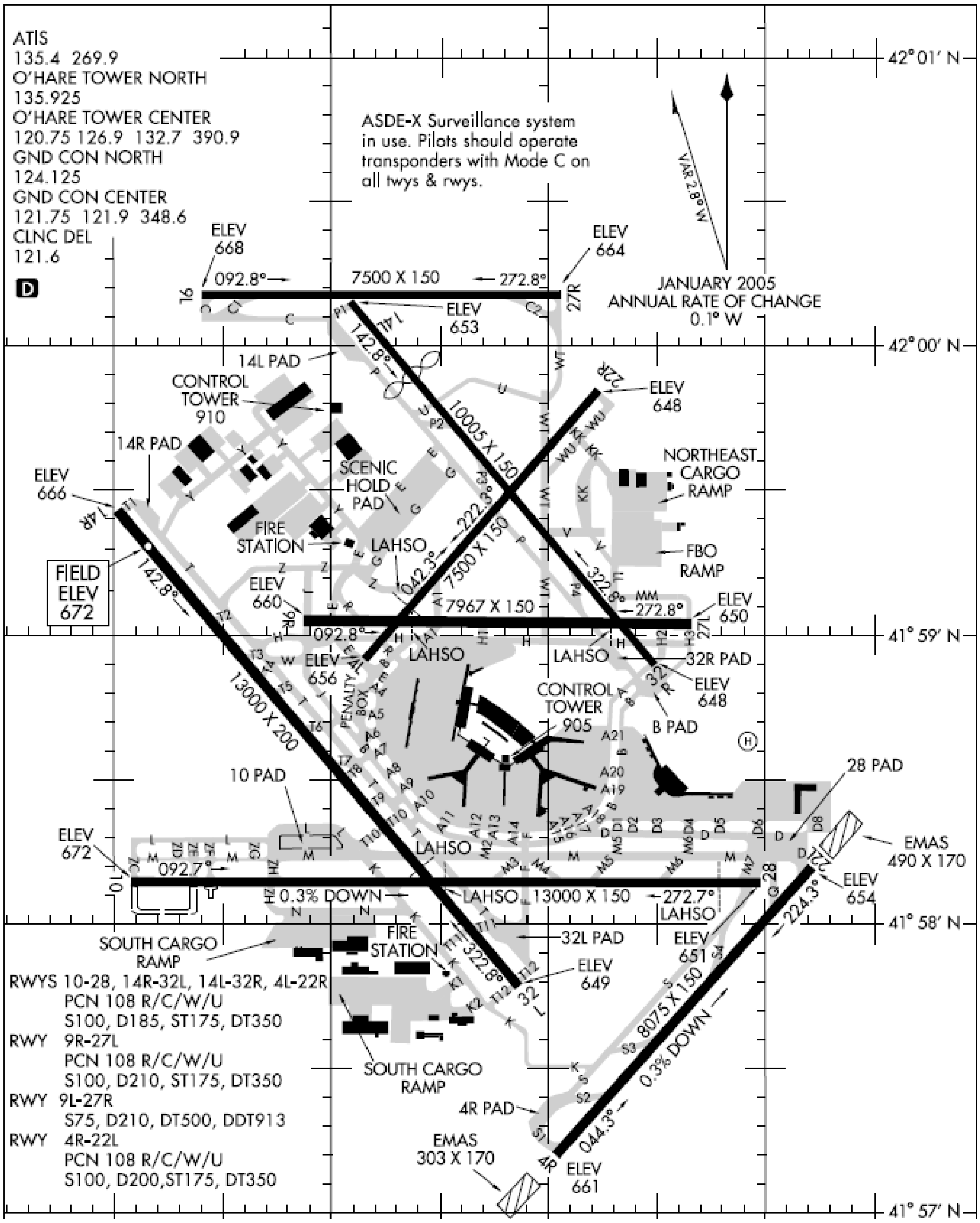

Figure 2: Chicago O'Hare (ORD) airport diagram

such as issuing clearances, alerting [aircraft] of runway obstructions, and providing separation assurance" (p. 2). Increased reliance on automation, digital communications, a shift from a tactical to a "strategic" control paradigm, and possibly providing services remotely might impact the aptitudes required of controllers for successful performance of their duties.

Controllers working in the FAA tower cab are responsible for the safe and efficient movement of aircraft and ground vehicles operating on the taxiways and runways of the airport itself, and aircraft in the air near the airport, generally within 2 to 5 nautical miles (nm; 3.7 to 9.2 kilometers (km)) of the airport, depending on the particular airport. The primary function of the tower cab is to separate aircraft landing or taking off from an airport and moving on the airport surface (Nolan, 1994). Separation in ATC refers to the physical and/or temporal distance, at a given time or location, between aircraft and other aircraft, vehicles, terrain, airspace, and other objects that might obstruct a flight. The primary tool to control the movement of aircraft and vehicles on the airport surface is the clearance. A clearance is a set of instructions issued to a specific aircraft, vehicle, or person. Common tower cab clearances are for a route of flight from origin to destination and for landing on or taking-off from a runway. Controllers also issue instructions for aircraft,

vehicles, and personnel to move from point A to point B on the airport surface. They also issue safety advisories and other information such as airport conditions and weather. Generally, clearances, instructions, and advisories from the tower cab controllers are issued by voice radio and are tactical in nature.

Tower cab clearances and instructions are tactical in three ways. First, a clearance is issued to a specific aircraft, vehicle, or person. Second, their geographic scope is generally limited to the airport surface and its associated airspace (the exception is the departure route-of-flight clearance, discussed below). Third, tower cab clearances and instructions are for actions to be taken within a limited time horizon, often just a few minutes. For example, an instruction to cross an active runway is generally a "do it now" rather than a "do in the next 10 minutes at your option" instruction.

Controllers in the cab continuously monitor and evaluate aircraft, vehicles, and personnel operating on and around the airport for separation and conformance to clearances and instructions. Other cab functions include assessing weather impact on ATC operations, disseminating information, advisories, and recommendations, operating airport taxiway and runway lighting systems, record-keeping, and coordinating with adjacent ATC facilities, airport authorities, and airlines as required.

CURRENT ORGANIZATION OF THE TOWER CAB

The tower cab is organized functionally around "working positions" that are staffed by on-duty controllers (FAA, 2010e). A working position in the cab is generally responsible for the surveillance, control, and communications with aircraft in specific areas of the airport and immediately adjacent airspace. The controller in each position provides specific services. There are generally four working positions in an air traffic control tower cab: Local Control, Ground Control, Flight Data, and Clearance Delivery. A Tower Supervisor is also on duty in the cab. The four working positions may be combined or split at the supervisor's direction. For example, the Flight Data and Clearance Delivery positions are often combined. A Traffic Management Coordinator position might also be staffed at large, complex hub airports.

Ground Control

The controller working the Ground Control position (sometimes referred to simply as "Ground") is responsible for the safe and efficient movement of aircraft and ground vehicles in the airport "movement areas." Movement areas generally include all taxiways, inactive runways, holding areas, and some transitional aprons or intersections where aircraft arrive, having vacated the runway or departure gate. Ground may also be responsible for the ramp areas, depending on airport configuration and complexity. There may be more than one Ground position for large, complex and busy airports. The exact specification of movement areas over which FAA exerts positive control varies with specifics of an airport and its operations.

Any aircraft, vehicle, or person moving, walking, or working in a movement area is required to have clearance from Ground. A clearance is a set of instructions issued to an aircraft, vehicle, or person for a specific operation such as taking off or inspecting a runway. Clearances are normally transmitted by Ground via VHF or Ultra-High Frequency (UHF) radio. Most importantly, Ground controls aircraft movements on the taxiways to and from the active runway(s). Ground influences the sequence of aircraft heading towards the departure runway. For example, if two aircraft call "Ready to taxi" at essentially the same time, Ground has discretion in determining which aircraft will be handled first. Ground might direct flight 123 to stop short of an intersection with a taxiway, and instruct flight 789 (already on the taxiway) to proceed through the intersection and on to the departure runway. Flight 123 would then turn onto the taxiway and follow flight 789 on out to the departure runway. Factors taken into account by Ground in determining the sequence of aircraft on the taxiways to the departure runway(s) include (but are not limited to) destination, route, departure fixes, runway loading, winds, aircraft size and weight, and associated wake turbulence constraints. Ground must also ensure that aircraft, vehicles, and pedestrians are appropriately separated while moving on the airport surface.

Local Control

The controller working the Local Control position (or, more simply, "Local") is responsible for the active arrival and departure runway(s). Local clears aircraft for takeoff or landing, ensuring that prescribed runway separation exists at all times. Communication and control of departing aircraft is transferred to the TRACON departure controller, provided the aircraft is properly separated from other traffic and is established in a normal climb. Arrivals contact tower on the Local frequency; Local clears the arrival to land on a specific runway (again, if and only if the aircraft is properly separated from other traffic or obstacles to a safe landing). Depending on the specific airport, Local will direct arriving aircraft to exit the runway at a specific point, usually a taxiway. Once the aircraft clears the runway, control and communication is transferred to Ground. A key responsibility for Local is to ensure that there are no obstructions or impediments to arriving and departing traffic. Sensibly, the runway must be clear of all other traffic for an aircraft to land or take-off. If the

controller working Local detects any unsafe condition, such as a vehicle intruding on the active runway or an aircraft that failed to exit the runway as directed, the next landing aircraft in the sequence may be told to "go-around" and be re-sequenced into the landing pattern. Known as runway incursions, unauthorized intrusions of aircraft, vehicles, or personnel onto an active runway are among the most serious and dangerous aviation errors.

Close coordination and continuous communication within the tower, especially between Local and Ground, is absolutely imperative. Generally, Ground must explicitly coordinate with Local to cross any active runway with any aircraft or vehicle. For example, when DFW is operating in what is known as the "South Flow" configuration, jet arrivals land from the north on the outboard runways labeled 17C, 17L on the east and 18R on the west side of the airport.[2] Departures take off to the south from the inboard labeled 17R on the east side and 18L on the west side (Figure 3). As a result, the arriving aircraft must cross the active departure runways to reach the terminals in the middle of the airport. The requirement to coordinate and communicate is reciprocal: Local must ensure that Ground is aware of any operations that will impact the taxiways or other movement areas in Ground's control.

Flight Data

Flight Data is responsible for ensuring that controllers and pilots have the most current airfield information: pertinent weather changes, outages, airport ground delays/ground stops, runway closures, etc. Flight Data may inform the pilots about airport information using Automatic Terminal Information Service (ATIS). ATIS is a recording of pertinent information broadcast in a continuous loop on a published frequency for that airport.

Clearance Delivery

Controllers working the Clearance Delivery position issue departure clearances to aircraft, typically before they commence taxiing. Clearances contain details of the route that the aircraft is expected to fly such as departure fixes (first fix after take off), waypoints along the route, and destination. The primary responsibility of Clearance Delivery is to ensure that aircraft have the proper route and departure "slot" time (that is, a specific time window in which to depart). This information is also coordinated with Ground and the appropriate en route center to ensure that the aircraft reaches the runway in time to meet the slot time provided by the national Air Traffic Control System Command Center. Clearance Delivery and Flight Data are often combined into a single position.

Tower Cab Team

Collectively, the four "standard" working positions and tower supervisor are known as the tower cab team or "cab crew." A tower may staff other working positions as needed. The FAA order governing ATC facility organization and operations (FAA, 2010e) lists as many as 17 different positions that might be filled in a tower cab. Positions can also be combined. However, it is important to note that controllers working in the cab must function as a team.

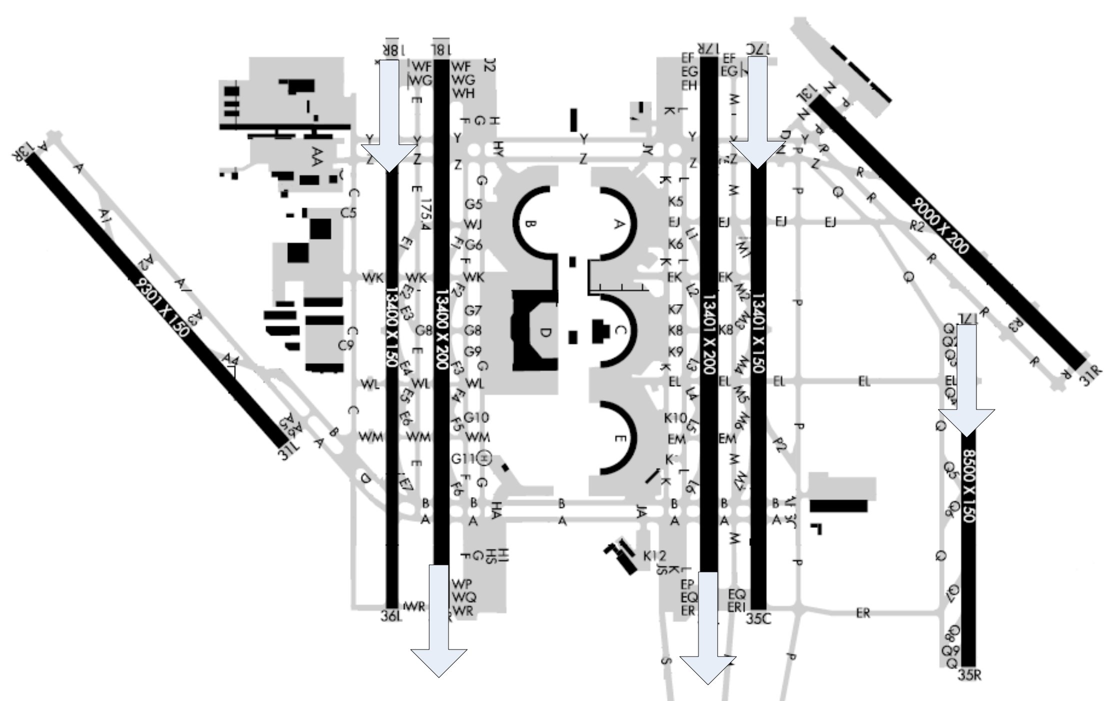

Figure 3: DFW in South Flow configuration (wind from the south)

Figure 4: CTRD in ORD tower cab

Paragraph 10-1-2 of the order reads

> There are no absolute divisions of responsibilities regarding position operations. The tasks to be completed remain the same whether one, two, or three people are working positions within a tower cab/facility/sector. The team, as a whole, has responsibility for the safe and efficient operation of the tower cab/facility/sector.

Current Equipment in the Tower Cab

The primary method of controlling traffic in the immediate airport environment today is visual surveillance (e.g., "out-the-window" [OTW] view) of movement areas by controllers from the tower. Basic facility equipment includes radios, telephones, weather instruments, (voice) recorders, airport lighting controls, Runway Visual Range (RVR) system, and the Flight Data Input/Output (FDIO) system. Multiple displays are available to the controllers in tower cabs, each associated with a particular system. These displays include the Certified Tower Radar Display (CTRD) and the Airport Surface Detection Equipment (ASDE) displays. CTRD (Figure 4) provides tower controllers with a visual display of the airport surveillance radar/beacon signals and data received from the terminal radar system, including airborne aircraft position, identification, radar beacon, and weather information. It is a high intensity display that can be seen by the tower controller even in a bright daylight environment. While CTRD provides information about airborne traffic, the ASDE displays information for traffic on the surface of the airport. The most modern ASDE system is the ASDE Model X (ASDE-X; Figure 5), which presents a 2-D map of the airport surface and allows the tower controllers to track surface movement of aircraft and vehicles. ASDE-X associates data tags with aircraft on the airport surface, using data from the aircraft flight plan. Finally, many towers have an Electronic Flight Strip Transfer System (EFSTS), which provides an electronic method for transferring flight information from the tower cab to other facilities such as the TRACON.

Current Workflow in the Tower Cab

The workflow in a tower cab is driven by the tempo of departures and arrivals, the communications required to handle the traffic, the mix of aircraft types and equipage, and airport layout. The work is also highly cyclical and repetitive, especially in high-volume hub airports dominated by air carriers operating commercial passenger and cargo flights. Example high-volume hub airports in the U.S.A. include ATL (the nation's busiest), ORD (second-busiest), LAX (third busiest), and DFW (fourth busiest). These airports typically have multiple runways and complex taxiways. Departures and arrivals are commonly scheduled by air carriers in overlapping "banks" at major airports. For example, a "bank" of 45 arrivals might be scheduled in the period 1200 to 1245. A bank of 36 departures might be expected between 1225 and 1310. The arrivals might be a mix of hub-to-hub traffic

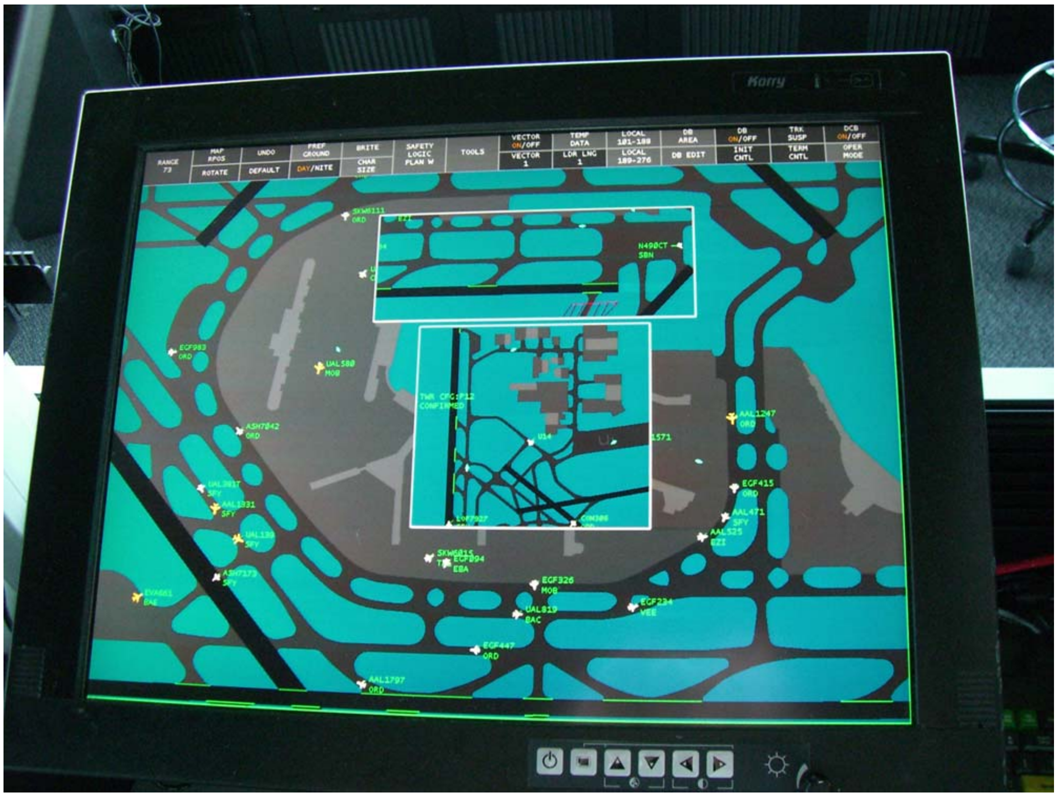

Figure 5: ASDE-X display (ORD)

and “feeders” from secondary markets to the hub. The departure bank would be a similar mix of hub-to-hub flights and flights to secondary markets. There might be a relative lull in the overall traffic, with a slower pace of arrivals and departures between 1330 and 1410, followed by overlapping banks for arrivals and departures starting at 1410. In the early part of the busy period, workflow is driven by the arrivals; towards the end the workflow is driven by departures. A major hub will experience many of these tides during the day.

To illustrate the workflow, single departures and arrivals will be used to describe the major tasks required of each position.

Single Aircraft Departure

The departure cycle for a scheduled flight operating under Title 14 of the Code of Federal Regulations (CFR) Part 121 (14 CFR 121) begins with the flight operator (either the aircraft pilot or a dispatcher in the Airline Operations Center [AOC]) filing a flight plan with the FAA. Depending on local procedures, a flight progress strip (FPS) is generated in the tower cab anywhere from 20 minutes to 2 hours before the scheduled departure. Example strips in both machine-generated and hand-written format are illustrated in Figure 6. Briefly, from left to right, the major blocks (columns) are aircraft information (items 1-4), assigned beacon code, proposed departure time, and requested altitude (items 5-7), departure airport (8), and route information (9). The Flight Data controller can also request a flight progress strip via FDIO. Flight Data reviews the flight plan as printed on the strip and makes amendments if required. Many (most) plans for scheduled commercial flights are filed far in advance. These “canned” flight plans might require amendments due to weather and other constraints on the day and at the time of the flight. Certain amendments to the filed route are made by the Air Traffic Control System Command Center before the flight strip is printed at the local tower. These amendments reflect imposition of constraints (known as Traffic Management Initiatives [TMIs]) such as holding flights for a specific destination on the ground at the departure airports and re-routes for entire flows of traffic to avoid severe weather. Other flight constraints are more airport specific, such as a runway closure.

After reviewing the flight plan and making appropriate amendments, Flight Data passes the departure strip to Clearance Delivery. Clearance Delivery issues the departure clearance via voice VHF radio to aircraft that do not subscribe to electronic delivery via Terminal Data Link Services (TDLS; FAA, 2008b). An IFR departure clearance includes specific, mandatory elements (Table 1). These are (a) aircraft identification, (b) a clearance limit, (c) the departure procedure, (d) the route of flight, (e) altitude, (f) departure frequency, and (g) the transponder code. After issuing the departure clearance, Clearance Delivery passes the flight progress strip to the controller working the Ground position.

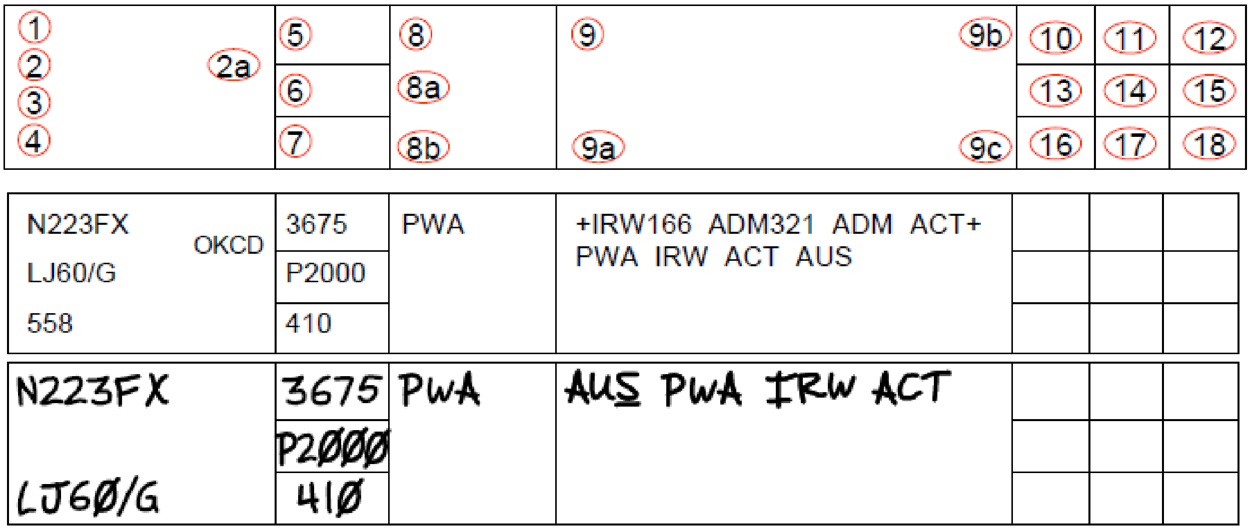

Figure 6: Flight Progress Strip (FPS) layout and example machine-generated and hand-written strips (from FAA Academy Initial Terminal Training: Stripmarking (TLP-11) (March, 2007)

Table 1: Example simple departure clearance

IFR Clearance Element	Example
Aircraft Identification	UNITED FIFTY-FIVE
Clearance Limit	CLEARED TO BURBANK AIRPORT
Departure Procedure	MARIC THREE DEPARTURE GORMAN TRANSITION
Route of Flight	VICTOR TWENTY-THREE, TWINE, DIRECT
Altitude	MAINTAIN FIVE THOUSAND, EXPECT FLIGHT LEVEL TWO ONE ZERO, ONE ZERO MINUTES AFTER DEPARTURE
Departure Frequency	DEPARTURE FREQUENCY ONE ONE NINER POINT ONE
Transponder Code	SQUAWK ZERO FOUR FIVE FOUR

When the flight is ready to depart, the pilot calls the tower on the Ground Control frequency (generally published on the airport diagrams as shown in Figure 2, upper left-hand corner). At some airports, the pilot contacts the tower cab to request pushback (or powerback where tugs are not available) from the gate. At the larger hub airports, more often the pushback from the gate is controlled by a Ramp Controller (employed by the flight operator or airport) rather than an FAA controller. At these large airports, the aircraft pushes back from the gate, and then taxis to what is known as a “spot.” A spot is the location at which the FAA assumes responsibility for control of the aircraft’s movement. The pilot calls Ground on the designated frequency and requests permission to taxi. Ground then issues instructions for the aircraft to taxi to the departure runway. Taxi instructions do not include the word “Cleared.” Rather, verbs such as “Taxi,” “Proceed,” “Continue,” “Follow,” “Cross,” and “Hold short of” are used. At a minimum, a taxi-out instruction will include (a) the departure runway for the aircraft, and (b) the taxi route: “Highline three fifty-nine, taxi to runway one eight left via taxiway Golf.” To reduce ambiguity and time required to issue taxi instructions at complex airports, a standardized or Coded Taxi Route (CTR) might be used. These are published procedures for specific airports, and essentially are shorthand for a series of discrete taxi instructions. So instead of saying, “Taxi to runway one-seven right via taxiway Juliet to Juliet 6, taxiway Bravo, then Whiskey,” the instruction would be given as “Taxi to runway one-seven right via Scenic.” Alternatively, Ground can issue progressive taxi instructions, in which instructions are given for each step of the taxi: “Highline three fifty-nine, taxi to runway one-eight left via Juliet, hold at Juliet Six and report.” Upon reaching the designated intersection, the aircraft would call Ground for additional taxi instructions: “Highline three fifty-nine, Continue taxi to runway one-eight left via Bravo, then Whiskey.” The departing aircraft executes the taxi instruction and Ground monitors the progress of the flight through the airport movement area by looking out the window and watching the ASDE display.

Under the current "First Come, First Served" control paradigm (see Paragraph 2-1-4 of FAA JO7110.65 (FAA, 2010b)), aircraft are handled in the order in which they contact Ground. However, Ground has a great deal of discretion in responding to aircraft calls and can manage the sequence of aircraft for the departure runway through a variety of tactics. The controller working Ground solves a real-time optimization problem with significant constraints, particularly at large, complex airports with varying mixes of aircraft. The overall optimization goals are to minimize taxi-out delay, maximize the departure rate, and to depart the aircraft on an efficient trajectory. At large hub airports, Ground manages this optimization problem though facility-specific Standard Operating Procedures (SOPs), "game plans," and experience. For example, an SOP might direct aircraft bound for the eastern half of the country (relative to the airport) to depart off a runway on the east side of the airport and west-bound aircraft to depart from a runway on the west side. This practice might entail using specific taxiways preferentially for most departures and anticipate congestion at a specific intersection. Informal "give way" or "right-of-way" rules might be applied to govern which aircraft proceeds through the intersection and which must stop for crossing aircraft. For example, departing "heavy" aircraft might have right-of-way through an intersection when established on a north-south taxiway but not in crossing from east to west. Similarly, Ground might "tee up" a series of four smaller aircraft such as two Boeing 737s and two McDonnell-Douglas Super 80s, followed by two "heavies" (such as a Boeing 747 and 777), followed by three smaller aircraft, and so forth. This sequencing allows the Ground to take advantage of the longer inter-departure interval between the heavies and the smaller aircraft to send arrivals across the active runway. In normal operations, Ground does not improvise new procedures on the fly, but rather uses well-established methods to manage the departure queue, minimize delay, and maximize throughput with a high margin of safety. In other words, the work is highly proceduralized. At present, those procedures are embodied as verbal instructions delivered over the radio to the aircraft by Ground Control. The tower cab staffing standards, in fact, are driven by the radio communications associated with aircraft operations (Schmeidler & D'Avanzo, 1994): More aircraft means more radio communications for Ground Control.

Upon arriving or nearing the active departure runway, the aircraft then contacts Local Control for actual take-off instructions. Local controls the active runway; aircraft must have positive permission from Local to be on or to cross an active runway. Local is also responsible for aircraft in flight within a few miles of the airport (usually 3 to 5 miles); generally, these aircraft will be departing, arriving, or circling the airport. Local issues the take-off clearance, which in its simplest form has just three elements: Aircraft ID (call sign), runway, and "cleared for takeoff." For example, a simple takeoff clearance would be "Highline three fifty-nine, runway one eight left, cleared for takeoff." Local must ensure positive identification of the aircraft and that the active runway is clear of obstructions, aircraft, vehicles, personnel, or other obstacles before issuing the takeoff clearance. With a queue of departures at the end of the active runway and taxiways supplying the runway, Local must consider the timing and conditions of each successive takeoff. For example, Local must wait a specified time before clearing any aircraft to takeoff behind a "heavy" aircraft (for example, a Boeing 747) due to wake turbulence. Aircraft might require turns to specific headings immediately after takeoff for noise reduction, avoidance of prohibited or restricted airspace, other traffic, and other reasons. In each instance, specific phraseology is required to accomplish the intended goal of a safe, efficient, and orderly series of departures. Once the departure is airborne and about 0.5 nautical miles beyond the runway end, Local instructs the aircraft to contact Departure (FAA, 2010b, Paragraph 3-9-3, Departure Control Instructions). Local scans the bar code printed on a machine-generated FPS to electronically transfer flight data to the departure controller.

Single Aircraft Arrival

Local Control manages the arrivals, often interleaving them with departures. At some large hubs, runways might be allocated solely or primarily to arrivals or departures by facility SOP or informal practices. For example, in the south configuration at DFW, Local might use 17 Right (the 1st runway on the east side of the airport) primarily for east-bound takeoffs (departures), and 17 Center and 17 Left for turbojet arrivals (see Figure 3). Takeoffs and arrivals are to the south in this configuration. At the basic level, a landing clearance has just three components: Aircraft ID (call sign); runway; and landing clearance: "Highline three ninety-five, runway one seven center, cleared to land." Additional instructions may be necessary, such as an instruction to hold short of another active runway that crosses the landing runway. After the aircraft lands, Local will issue runway exiting instructions and possibly an instruction on when to contact the Ground Control. For example, an aircraft landing to the south on 17C at DFW might be instructed to turn right and exit the runway at the Mike Six (M6) high-speed turnoff, cross taxiway Mike (between 17C and 17R), hold short at the Echo Mike (EM) intersection with runway 17R, and to contact Ground on the appropriate radio frequency: "Highline three ninety-five, runway 17 center, cleared to land. Turn right at Mike Six, cross taxiway Mike, hold

short of runway 17 right at Echo Mike, contact Ground point seven four." The arriving aircraft in this scenario lands from north to south on 17C, exits the runway at M6 with a right hand turn, crosses taxiway M between the two runways, stops just east of the departure runway 17R at the intersection labeled Echo Mike, switches to the frequency, and contacts Ground. The pilot reports the current position and intended destination (gate, terminal, hangar, or other location on the airport). In this example, the arrival is headed for a specific gate, as directed by the flight operator. Ground coordinates with Local to have the arrival ("Highline three ninety-five") cross the active departure runway (17R), and then issues the appropriate crossing and taxi instruction to get the aircraft to the appropriate "spot." On nearing or reaching the "spot" nearest the company assigned gate, the aircraft switches to its company frequency. The associated electronic record for the flight is then closed out and archived.

Multiple Aircraft Operations

While the basic flow is relatively straightforward for a single departure or arrival, the reality is far more complex with multiple aircraft in different phases of the operation, especially at large hubs with overlapping banks of arrivals and departures. Controllers, particularly when working the Ground and Local positions, are responsible for multiple aircraft at any given moment in a mix of arrivals and departures on the active runways and taxiways. For example, the Local Controller might issue a landing clearance to an aircraft several miles out on final approach to the arrival runway, then turn her attention to issue a takeoff clearance to an aircraft in the queue for departures, and then coordinate with the Ground to clear several aircraft across the active departure runway, all within a minute or less. Similarly, Ground Control might have an arrival waiting for clearance to cross the active departure runway, two departure aircraft calling from the transfer-of-control "spots" at the boundary between the airline's ramp and the FAA's movement areas, ready to begin their taxi, three aircraft established on the taxiway to the departure runway, and two inbound aircraft taxiing toward the terminal.

The Local and Ground controllers maintain an active scan of their areas of responsibility (FAA, 2010b, Paragraph 3-1-12, Visually Scanning Runways). The locations of aircraft, vehicles, and other objects relative to expectations and intentions are constantly evaluated and actions taken as needed by the controller. For example, the controller working Ground might evaluate the relative taxi speed of two aircraft heading towards the same intersection, and issue an instruction to one aircraft to "give way" to the other. Similarly, Local might shift attention to a departing aircraft to determine its progress and if it has rotated for take-off as a visual cue to issuing a take-off clearance for the next aircraft in the departure queue. In both examples, the sequence of behaviors associated with each clearance or instruction is completed (or completed through a certain point), and the scan of the area under the controller's responsibility is resumed. External events might trigger another behavioral sequence such as an aircraft checking in on the GC frequency with a "ready to taxi" call. On completion of that behavioral sequence, the controller returns to monitoring and evaluating the movement and positions of objects, ready to take action as needed to ensure the safe, efficient, and orderly flow of traffic into, on, and out of the airport.

Current Job/Task Analyses

The work done by controllers in today's NAS has been described in several formal analyses. The most relevant analyses are (a) the Computer Technology Associates, Inc. (CTA, Inc.) operations concepts analyses from the late 1980s (see Alexander, Alley, Ammerman, Fairhurst, Hostetler, Jones & Rainey, 1989; Ammerman, Becker, Jones, Tobey, & Phillips, 1987), (b) observational studies by Booz, Allen, Hamilton, Inc. (2006), Durso and colleagues (Durso, Sethumadhavan, & Crutchfield, 2008; Durso, Fleming, Johnson, & Crutchfield, 2009), and Pinska (Pinska & Bourgois, 2005; Pinska, 2006); (c) an "update" of the CTA, Inc. description by the American Institutes for Research (AIR®; Krokos, Baker, Norris, & Smith, 2007); and (d) the University Research Corporation (URC) selection-oriented job/task analysis (Nickels, Bobko, Blair, Sands, & Tartak, 1995). The CTA, Inc. analysis has become the de facto "standard" job/task analysis for air traffic control in the FAA for describing the work of controllers in centers, TRACONs, and towers. For example, FAA instructional system designers used the CTA, Inc. descriptions as the starting point for identifying changes in controller tasks with new technologies and procedures such as the User Request Evaluation Tool (URET) and the Airport Movement Area Safety System (AMASS; R. Welp, personal communication). Similarly, the 1995 Nickels et al. analysis of worker requirements has become the de facto standard catalog of aptitudes required at the time of hire into the ATCS occupation in the FAA.

CTA Inc. Operations Concept Analysis for the Tower Cab

The goal of the CTA, Inc. operations concept analysis was to describe how future controller work would be performed in the Advanced Automation System (AAS). CTA, Inc. produced a series of volumes describing (a) the "as is" (as of the late 1980s) for controller work in the tower, TRACON, and center, (b) the knowledge required in the "as is" NAS (as of the early 1990s), and (c) the "to

Table 2: Five levels of description used by Ammerman et al. (1987, 1989)

Level	Description
Activity	A group of related sub-activities
Sub-activity	The operations performed in response to a single event
Task	The smallest discrete unit of human behavior that can be fully understood within the general context of the job environment
Task Element	A single identifiable step in the performance of a task
UIL	(a) Operational data and control messages entered into the system in performance of a specific task element; (b) graphical and alphanumeric displays, written and printed messages, alerts, alarms and other signals for controller attention.

Table 3: High-level activities by position from the CTA, Inc. ATCT operations concept analysis

Local Control	Ground Control	Flight Data/Clearance Delivery
Perform local situation monitoring	Perform ground situation monitoring	Perform clearance delivery/flight data situation monitoring
Resolve conflict situations	Control aircraft/vehicle ground movement	
Manage air traffic sequences		Manage air traffic sequences
Route or plan flights	Route or plan flights	Route or plan flights
		Respond to flow constraints
Assess weather impact	Assess weather impact	Assess weather impact
Manage local controller position resources	Manage ground controller position resources	Manage clearance delivery/flight data controller position resources
Respond to system/equipment degradation	Respond to system/equipment degradation	Respond to system/equipment degradation

be" for controller work in AAS facilities such as the Tower Control Computer Complex (ATCT/TCCC; Ammerman, Becker, Bergen, Claussen, Davies, Inman, et al., 1987). The CTA, Inc. operations concept analysis is similar to a hierarchical task analysis (HTA; see Annett, 2004), a widely used method for representing the work performed by humans in a system. However, CTA, Inc. developed a graphical depiction of the work performed by controllers, a full decade before commercially-available job/task analysis applications began incorporating that capability. The graphics depict operational events or conditions that trigger different sequences of controller actions and also show the inherently cyclical and repetitive nature of the work.

In the CTA, Inc. operations concept analyses, controller work is described at five levels, as shown in Table 2. The highest level of description is an "Activity" in their approach. An ATCS activity is a major job duty or function. The work of controllers at a working position is described with five to nine activity statements. Each activity is decomposed by Ammerman et al. into five to nine "Sub-activities." Sub-activities are decomposed into tasks, and, in turn, tasks are decomposed into task elements.

The task is the focus of the CTA, Inc. analysis of controller work. A task is a concise, specific statement of what is accomplished by a person in a specific operating environment and position, with a clear beginning and ending, with sufficient detail to understand what is accomplished without enumerating the minor, procedural steps required in performing the task (Ammerman, et al., 1987). All descriptions of controller work in the CTA, Inc. analysis take the form of a verb-noun (object) phrase, with modifiers appropriate to the context for a particular work statement. The procedural steps are "task elements" in the CTA approach. The lowest level of description is the User Interface Language (UIL), which refers to (a) the operational data and control messages entered into the system by the controller in the performance of a task element and (b) the graphical displays, alphanumeric displays, written and printed messages, and alerts, alarms, and other signals for controller attention. Display contents and controller message entries cataloged in the UIL are used as the objects in the verb-object statement that constitutes a task element.

The high-level activities originally defined by CTA, Inc. for CD/FD, Ground, and Local control are presented in Table 3. There are redundancies in the activities across

the three working positions. For example, controllers in all three positions "Route or Plan Flights." While there are differences by position, especially at the task element and UIL levels of analysis, the actual work is very similar. In routing or planning flights, a controller considers information about the flight, selects a course of action, ensures that the planned action is safe, and communicates that action to the aircraft directly or for relay by another controller. Local might rely upon the CTRD, flight progress strips, and out-the-window observations, while Ground looks at the ASDE(-X) display, strips, and out-the-window view as information sources.

Observational Studies of the Tower Cab

Observational studies focused on controller behaviors in the tower cab. For example, Pinska (Pinska & Bourgois, 2005) reported that looking out the tower windows occupied 30 to 40% of controller time in the tower cab. Other frequently used information sources were flight progress strips and radar displays. Further study confirmed these results (Pinska, 2006). Booz, Allen, Hamilton, Inc. (2006) collected observational data at seven towers to identify information needs and sources. The analysts reported that the out-the-window view, flight progress strips, and radar displays (both air and surface) were the most frequently used information sources. Durso and colleagues (Durso et al., 2008, 2009) investigated the use of paper flight progress strips for each working position in the tower cab. While some strip marking might be characterized as primarily "bookkeeping," the marks were also useful to the controllers to reduce workload, and to aid communications, memory, organization, and situation awareness. While these studies highlight aspects of work behavior, they were not full-scale job analyses to support identification of aptitudes.

AIR® 2007 Update for the Tower Cab

Krokos, Baker, Norris, and Smith (2007), on the other hand, reviewed the CTA, Inc. descriptions down to the task level of analysis and endeavored to consolidate the activities, sub-activities, and tasks into a single, integrated description of the work of a controller in the tower cab across the working positions. The result is a functional rather than positional analysis. AIR® described the work of controllers in terms of eight activities: (1) Perform situation monitoring, (2) Resolve aircraft conflict situations, (3) Control aircraft or vehicle ground movements, (4) Manage air traffic sequences, (5) Route or plan flights, (6), Assess weather impact, (7) Manage controller position resources, and (8) Respond to system/equipment degradation. These job activities provide a useful way to organize the description of tower controller work for the purpose of this paper.

1995 Selection-oriented JTA

The operations concept analyses, observational studies, and the 2007 update focused on describing the work of tower cab controllers. While useful, personnel selection requires a specification of the knowledge, skills, abilities, and other personal characteristics (KSAOs) as well. The FAA, at least at present and in the foreseeable future, selects new controllers on their aptitude rather than demonstrated ATC-specific knowledge and skill. Aptitude, in this usage, refers to the set of innate and acquired abilities and other characteristics a person possesses at the time of hire, and for which the employer provides no explicit training or development. The most recent analysis of the aptitudes required to enter the ATCS occupation was the 1995 job/task analysis to support the Selection and Control Hiring Assessment (SACHA; Nickels et al. in 1995). That formal, selection-oriented job/task analysis identified 67 "worker requirements" based on psychological and ATC research. Incumbent controllers rated the importance of each worker requirement to learning and doing the job. Nickels et al. analyzed the ratings by type of facility: air route traffic control center (ARTCC), terminal (including cab and TRACON), and flight service station. The importance ratings were also analyzed by job assignment and facility level within the terminal option. The three job assignments were ATCT cab only, TRACON only, and ATCT cab and co-located TRACON ("up/down" facilities). Overall, there was a high level of agreement in the ratings of the importance of the worker requirements across the three job assignments within the terminal option.

The list of worker requirements (aptitudes) identified by the 1995 job analysis are presented in the Appendix, sorted by average importance (IMP) to doing the job (from high to low). Importance was rated on a 0 to 5 (i.e., not needed to extremely important) scale by a sample of job incumbents (n=389). The importance ratings were also analyzed by working environment (ATCT cab, TRACON, and ARTCC). In comparing ATCT cab and TRACON, the study authors concluded that "…there were no substantive differences in the relative rankings of the worker requirements across the job assignments within the Terminal option, and that these assignments can be considered to be quite similar for purposes of <u>selection</u>" (p. 158; emphasis added). Similarly, in considering the rank ordering of worker requirements across working environments (e.g., ATCT, TRACON, and ARTCC), the authors concluded, "From a <u>selection</u> perspective there appear to be no substantial differences between ARTCC controllers and ATCSs working Terminal option by job assignment" (p. 159, emphasis added). In other words, there is a common profile of aptitudes required for <u>selection</u> into the ATCS occupation (but the differences in importance by working environment might be useful for

placement purposes). As the focus of this paper is selection into the ATCS occupation, the overall profile of aptitudes derived by Nickels et al (1995) is adopted as the baseline for this analysis. The analytic question addressed in this report is "How and to what degree mid-term NextGen technologies and procedures change that occupational profile in the tower cab?"

Baseline Aptitude Profile

Of the 67 worker requirements evaluated in the 1995 job/task analysis, 29 had an average rating of four ("Very important to doing the job") to five ("Extremely important to doing the job").[3] These aptitudes can be loosely organized, for explanatory purposes only, in terms of an input-process-output model (Figure 7[4]). The abilities related to the "input" side are visual perception and auditory perception; sight and hearing are fundamental to success in air traffic. The specific visual abilities important to work in the tower cab are (a) *Scanning* and (b) *Perceptual Speed and Accuracy*. *Scanning* in the 1995 analysis was defined as the "ability to quickly and accurately visually search for information (e.g., on a computer screen, radar scope, flight strip bay, runway, on the horizon)." In other words, tower cab controllers must have the ability to visually search multiple sources of information, including the out-the-window view, radar display, surface display, flight strips, and other visual elements. The controllers must be able to "perceive visual information quickly and accurately," otherwise known as demonstrating *Perceptual Speed and Accuracy*. The third "input" is labeled *Active Listening*. This ability was defined by controllers and psychologists in the 1995 analysis of worker requirements as the ability "to hear and comprehend spoken information." This analysis is sensible in that even a cursory consideration of the work of tower cab controllers would conclude that it is dominated by visual and auditory stimuli. It makes sense, then, that controllers would need the ability to see and hear those stimuli.

However, a finer distinction can be made. Controllers in the tower cab are flooded with information in the visual and the auditory channels. The definition of *Active Listening* in the 1995 analysis includes "…the ability to recognize or pick out pertinent auditory information." In other words, auditory attention (i.e., *Active Listening*) is part of the profile of aptitude for the ATCS occupation. One can argue that the same qualification is made for visual information: It is important for controllers to have the ability to selectively attend to (quickly and accurately) the relevant visual elements that are "pertinent" to the task at hand.

The primary output for controllers is speech, or in the 1995 lexicon, *Oral Communications*. There are also motor outputs, as shown in Figure 7, in terms of writing, typing, and using a computer mouse, but they pale in significance compared to talking on the radio and telephone. Controllers in the current tower cab rely upon speaking clearances and instructions over the radio. Of the 184 tower controllers participating in the 1995 job analysis survey, two-thirds rated *Oral Communications* as "Extremely Important – Lack of this ability will seriously jeopardize [your] ability to do the job." In contrast, just 21 of those tower controllers rated the ability to write (*Written Communication*) as "Extremely Important." The 1995 analysis qualifies the definition of *Oral Communications*: "Projecting a confident tone of voice is an important component of this ability." However, as with the "ability to quickly and accurately" pick out the visual and auditory input elements relevant to the situation at hand, it is not clear if the implied "ability to project a confident tone of voice" is innate, learned and developed in job-related training, or some mixture of both.

The abilities required to process the visual and auditory input and produce the spoken outputs (clearances, instructions, and advisories) are both more numerous and more complicated to describe. Of the 29 abilities rated as very or extremely important, 19 were cognitive in nature and six can be described as personality traits or perhaps cognitive style. As with every description of human cognition, memory was a key aptitude. In particular, *Short-term Memory* was rated by 83% (152 of 185) of the tower controllers as "Extremely Important" or "Very Important" to their job performance. *Long-term Memory* was rated by about two-thirds of the tower controllers as very or extremely important. Even casual observation of the job would suggest that both "types" of memory are fundamental abilities required of controllers. On one hand, the situation in which they work is fluid and dynamic, with a cast of actors that changes within just a few minutes. On the other hand, controllers must memorize a large body of rules and procedures, a specialized vocabulary and syntax (to orally produce the highly formatted clearances, instructions, and advisories), and uniquely, a spatial map of an airport and its airspace. However, the job analysis did not further refine or explore finer distinctions in these two commonplace cognitive constructs.

From an input-process-output perspective, the important perceptual abilities – *Active Listening* (including Auditory Attention), (visual) *Scanning*, and (visual) *Perceptual Speed and Accuracy* – are shown in Figure 7 as feeding into *Short-term Memory*. *Long-term Memory* underlies the entire "process" block as containing the declarative and procedural knowledge required to perform the tasks of a tower cab controller.

For explanatory purposes only, the next set of cognitive abilities can be framed as those relating to attention. Cab controllers must focus or attend to pertinent

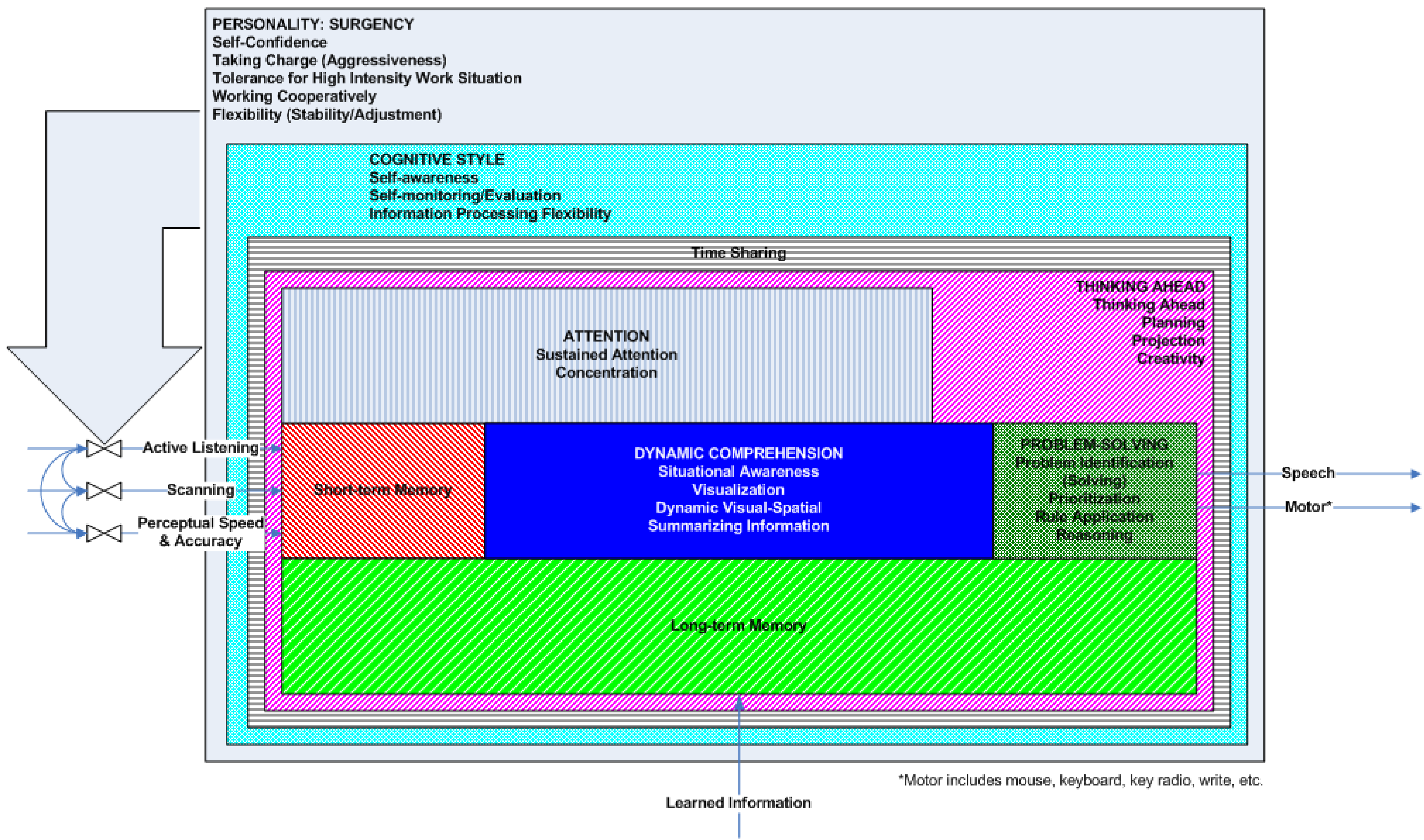

Figure 7: Heuristic ATCS aptitude input-process-output model

information embedded in multiple auditory and visual streams of information in a very dynamic situation. Two aspects of attention were rated, on average, as very or extremely important to doing the job by three-quarters of the incumbent tower controllers participating in the job analysis survey: *Sustained Attention*; and *Concentration*. *Sustained Attention* was defined in the job analysis survey as the "ability to stay focused on a task(s) for long periods of time (over 60 minutes)." The second construct, *Concentration*, was defined as the "ability to focus on job activities amid distractions." *Sustained Attention* explicitly references duration, while *Concentration* appears to reflect the intensity of the controller's focus on the task at hand.

Given perceptual input into *Short-term Memory*, declarative and procedural knowledge retrieved from *Long-term Memory*, and attention to those events, the next step, for explanatory purposes only, is to comprehend the meaning of the dynamic situation. While this step seems to be sequential, in fact it is a dynamic and on-going cognitive process. Controllers often describe this as "getting the flick" or "seeing the problem." Anecdotally, some describe the awareness in terms of directing a movie, a state in which they visualize where the actors (aircraft and vehicles) will be in the next few frames. A more psychological term is dynamic comprehension, that is, the understanding of a dynamic, changing situation. The relevant abilities rated by controllers, on average, as very or extremely important, were *Situational Awareness*, *Visualization*, *Dynamic Visual-Spatial*, *Flexibility (in Information Processing)*, and *Summarizing Information*. *Situational Awareness* was defined in the job analysis survey as the "ability to be aware of, and to integrate, all relevant information within a four-dimensional (three dimensional plus time) space (e.g., getting the picture)." *Situational Awareness* as a psychological construct is not without controversy (Tenney & Pew, 2006) but has been widely adopted in the aviation community. Not unsurprisingly, given the phrase "getting the picture" in the definition, a large majority (85% of 202) of tower controllers rated *Situational Awareness* as very or extremely important to job performance. *Visualization* in the 1995 job analysis was defined as the ability "to translate information into a visual/mental representation of what is currently occurring," with 83% of tower controllers indicating this ability was very or extremely important. Other abilities related to "getting the picture" that were less strongly endorsed include *Summarizing Information*, *Dynamic Visual-Spatial*, and *Flexibility (in Information Processing)*. *Summarizing Information*, defined as the ability "to summarize and consolidate information most relevant to the situation;" 70% of participating controllers marked it as very or extremely important. *Dynamic Visual-Spatial* was defined as the ability "to interpret the movement of objects in space." For example, cab controllers observe the movement of aircraft and vehicles in, on, and around the airport. About two-thirds (68%) of cab controllers marked this ability as very or extremely important. Cab controllers construct a representation of the dynamic traffic situation by using these abilities.

At the same time, cab controllers also identify problems such as an immediate or possible loss of separation. While Figure 7 suggests a sequence of cognitive operations, in fact, problem identification and solving occurs simultaneously with dynamic comprehension. Several abilities are grouped under the general heading of problem solving, for expositional purposes only. The construct Problem Identification (Solving) forms the core of this set of abilities. Nickels et al. defined this as the "ability to identify a potential or existing problem and to identify the variables used in solving the problem." A large majority (88%) of terminal controllers rated this ability as very or extremely important to job performance. Reasoning, defined as the "ability to apply available information in order to make decisions, draw conclusions, or identify alternative solutions," is another aspect of problem solving; 87% of terminal controllers rated this as a very or extremely important ability. In most cases, a controller selects a learned procedure or rule to apply to the situation at hand. The 1995 job/task analysis termed this Rule Application, and 82% of terminal controllers rated this as a very or extremely important ability. Deciding which rule to apply implies conditional, logical "if-then" reasoning. For example, if the departing aircraft is "heavy" (such as a Boeing 747), then the next departure must wait 3 minutes before departing to ensure safe separation from any wake turbulence generated by the departing 747. Sometimes, however, a unique or unusual situation arises for which existing procedures or rules don't apply or simply don't exist. Some degree of Creativity, defined as the "ability to identify new or novel solutions to potential problems when existing or established solutions no longer apply," might be required. More than two-thirds of the controllers (69%) rated this aptitude as very or extremely important.

The next group of aptitudes, for explanatory purposes, relates to the notion of thinking ahead. Air traffic control is very future-oriented: What might happen, at a time horizon measured in minutes from now, is important; what has happened is largely irrelevant. Controllers sometimes describe this as "being ahead of the problem." Three aptitudes are grouped here for explanatory purposes only: Projection; Thinking Ahead; and Planning. Thinking Ahead was defined in 1995 as the "ability to anticipate or recognize problems before they occur and to develop plans to avoid problems. This includes thinking about what might happen." Almost all (93%) controllers rated this as a very or extremely important aptitude. Projection has a

somewhat different sense as it was defined as the "ability to translate material into a visual representation of what will occur in the future." For example, a cab controller might see where two aircraft are in relation to each other on two taxiways and the end of the departure runway, and then by Projection, develop an internal representation of where the two aircraft will be in two or three minutes. Most (86%) controllers indicated this was a very or extremely important aptitude to doing the job. Finally, Planning was defined as the "ability to determine the appropriate course(s) of action to take in any given situation." This aptitude is very closely related to the abilities grouped under the "Problem-solving" umbrella. However, the focus of "problem-solving" is the present, while the focus of Planning is the future. As might be expected, nearly all (93%) controllers rated Planning as a very or extremely important aptitude.

These aptitudes are used in a dynamic setting, often requiring the controller to appear to be doing two or more activities at once. Regardless of the technical niceties in the definition of "multi-tasking" or "time-sharing" as being either truly simultaneous activities or (merely) rapid attention-shifting between activities, controllers are required to perform multiple activities in very short time periods. From an observational perspective, controllers often seem to be doing two things at once in the tower cab. For example, the Ground controller might be talking on the radio, issuing a clearance, while also marking one or more flight strips, or perhaps re-sequencing an array of flight strips. As shown in Figure 7, the ability to multi-task overlies the input-process-output model for controller abilities. The 1995 job/task analysis used the term "Time Sharing," which was defined as the "ability to perform two or more job activities at the same time." Some 87% of terminal controllers participating in the 1995 job/task analysis survey marked this aptitude as very or extremely important to doing the job of a controller.

At a higher order of description, three groups of abilities (aptitudes) –Dynamic Comprehension, Problem-solving, and Thinking Ahead – at the core of this expository model are consistent with the construct Fluid Intelligence (symbolized as Gf in the individual differences literature) as described in the Cattell-Horn-Carroll (CHC) model of human abilities. McGrew (2009) described Gf as "The use of deliberate and controlled mental operations to solve novel problems that cannot be performed automatically." Example mental operations encompassed within Gf include comprehending implications, problem solving, transforming information, generating and testing hypotheses, identifying relations, extrapolating, inductive and deductive reasoning (McGrew). In other words, based on the 1995 job/task analysis, Gf is central to the human abilities (aptitudes) required of air traffic controllers.

The remaining abilities (aptitudes) also can be thought of as providing a framework or context for controlling air traffic. These abilities have more to do with person-job and person-environment "fit" than the technical work itself. Nonetheless, controllers rated these abilities as very or extremely important to the job. The first set has to do, for lack of a better descriptive label, with a controller's cognitive style. Like pilots, controllers must continuously monitor, evaluate, and, if necessary, change their behavior in response to their operational environment. Self-awareness was defined as the internal awareness of one's actions and attitudes – and limitations. About three-quarters of controllers (77%) marked this as a very or extremely important aptitude. Self-monitoring/Evaluation is a closely related aptitude, defined in the 1995 analysis as the ability and, importantly, willingness to check one's work, evaluate the effectiveness of decisions, and alter performance if necessary. Self-monitoring/Evaluation has the sense of doing something about or with one's internal self-awareness. Some 73% of controllers marked this aptitude as very or extremely important to performing the job. Making that adjustment implies a degree of flexibility. This is reflected in the construct Flexibility (Information Processing), which was defined as the "ability to find new meanings for stimuli, to combine stimulus attributes to come up with new and different solution protocols, and to employ flexible ways of relating new information to stored knowledge." Most (61%) controllers considered this to be a very or extremely important aptitude.

The final set of abilities, for explanatory purposes, is related to personality and interpersonal style. One of the striking things about controllers is their self-confidence and self-assurance, as reflected in this set of abilities. Overall, they have the distinct flavor of surgency. While surgency can be thought of as a facet of the broader construct of Extroversion in the Five-Factor Model of personality, it is used more specifically here as a label for constructs such as self-confidence. Self-confidence was defined in the 1995 job/task analysis as the belief "that you are the person for the job and knowing that your processes and decisions are correct." A large majority of controllers (72%) marked this as a very or extremely important aptitude. A related aptitude is Taking Charge (Aggressiveness), defined as the "ability to take control of a situation—to reach out and take correct action." This aptitude speaks to the willingness of the controller to "step up" instead of "hiding from the problem." This self-confidence and aggressiveness is tempered or balanced by two other abilities. Flexibility (Stability/Adjustment), defined as the "ability to adjust or adapt to changing situations or conditions," was endorsed by 81% of terminal controllers in the 1995 job/task analysis survey. The other aptitude relates to the simple fact that controllers rarely work alone

and must cooperate with others to accomplish their mission, especially in the tower cab. Working Cooperatively, defined as the "willingness to work with others to achieve a common goal," was endorsed by 79% of participating controllers. Working Cooperatively also encompassed the notion of providing assistance to another controller if the situation warranted. The last aptitude construct focuses on the reaction of the individual to the perceived demands of the job. The construct Tolerance for High Intensity Work Situations was defined as the "ability to perform effectively and think clearly during heavy work flow." Almost all (96%) terminal controllers participating in the 1995 job/task analysis rated this aptitude as very or extremely important to job performance.

THE TOWER CAB IN 2018

The next step in the strategic job analysis is to consider how the work of the controllers in the tower cab might change by 2018. First, information from the FAA's NAS Enterprise Architecture (NAS EA; FAA, 2010f) is evaluated to determine the overall organization of the tower cab in terms of working positions. Then the workflow in the mid-term tower cab is described. This description is derived from available concepts of operation and use of new controller technologies, HITL simulation reports, and other artifacts. Key technologies such as DSTs are described in this sub-section. Then, as in the analysis of the current tower cab, the aptitudes likely to be required of tower cab controllers in the mid-term are described.

Tower Cab Organization in 2018

The first question is how the tower cab might be organized in the mid-term in terms of working positions and general responsibilities. To answer this question, the most recent iterations of the NAS EA, service, infrastructure, and human-systems integration roadmaps were reviewed, along with the accompanying OV-5 (Operational Activity Model, dated January 29, 2010) and OV-6c (Operational Event Trace Description, dated March, 2010) views. The first page of the human-systems integration roadmap is reproduced in Figure 8. It appears that, as in the current organizational paradigm, the tower cab in 2018 will be organized around the working positions in use today: Ground Control, Local Control, Flight Data, and Clearance Delivery.

Ground Control remains the linchpin for the safe and efficient flow of traffic on the airport surface in the mid-term. In the NAS EA Operational Activity Model (OV-5), "The ground controller is responsible for separating aircraft and vehicles operating on taxiways and other airport surface areas (not including active runways" (Appendix A, p. 58). Ground responds to pilot taxi requests and issues instructions. Local, in the NAS EA OV-5, "has primary responsibility for operations conducted on the active runway and must control the use of those runways." Local's responsibility "includes positive coordination with Ground Controller, monitor and control of vehicles using/crossing runways" (Appendix A, p. 58). The controller in Clearance Delivery position will be responsible for reviewing, updating, and issuing the flight clearance. However, the tools used by the controller working Clearance Delivery will change, as discussed in more detail below. In particular, Clearance Delivery will rely on electronic flight strips and digital, text-based messaging, although radio and telephone services will still be available. Flight Data responsibilities are unlikely to change in the mid-term. In the NAS EA OV-5, Flight Data will operate interphones (e.g., dedicated telephone lines between facilities and positions), process and forward flight plan information, compile statistical data, observe and report weather information, "assist [the] tower cab in meeting situation objects" (Appendix A, p. 59).

Tower Cab Equipment in 2018

Two significant changes in tower cab equipment can be expected by 2018: Data communications ("DataComm") and new automation in the form of DSTs. At the same time, the number of display screens (CRT and LCD) in the cab will be reduced by 2018.

DataComm

The FAA has long planned to shift from voice to digital, data communications. For example, Wayman Deal wrote in 1962 that the "application of digital techniques to aeronautical air traffic control communications has been under study in the United States for more than fifteen years." Almost five decades later, data communications (DataComm) is a transformational technology and a key component of NextGen. As described by the FAA, DataComm will "assume an ever increasing role in controller to flight crew communication" and eventually become the predominant mode of communication between the air crews and controllers. FAA (2009a) describes DataComm this way:

> Data Comm will provide comprehensive data connectivity, including ground automation message generation and receipt, message routing and transmission, and aircraft avionics requirements. Data Comm will automate repetitive tasks, supplement voice communications with less workload-intensive data communications, and enable ground systems to use real-time aircraft data to improve traffic management efficiency. Initially, data communications will be a supplemental means for two-way exchange between controllers and flight crews for air traffic control clearances, instructions, advisories, flight crew requests and reports. As data communications becomes the new method

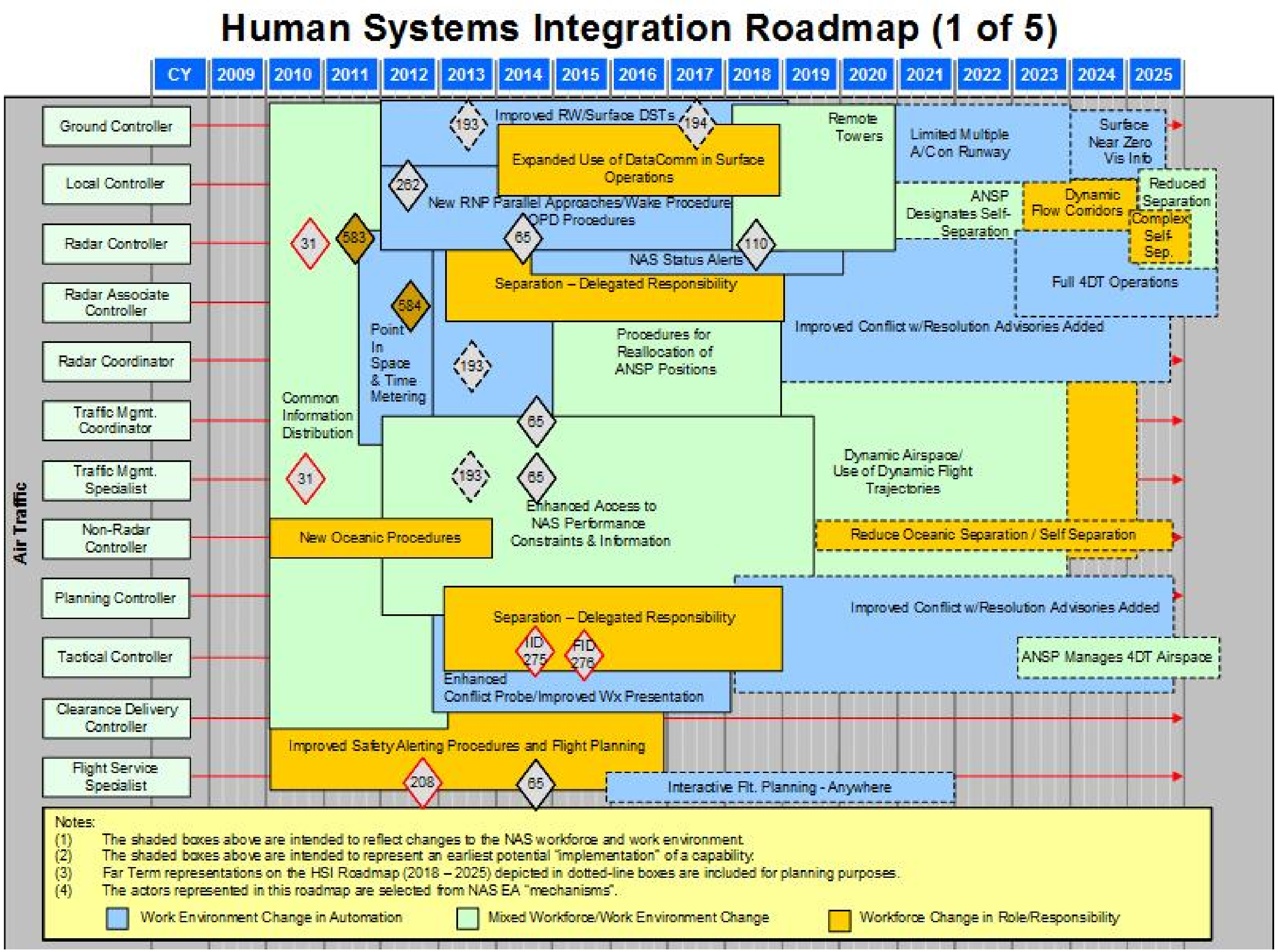

Figure 8: ATCT Positions in the NAS EA Human Systems Integration Roadmap

of operation, the majority of air/ground exchanges will be handled by data communications for appropriately equipped users. Automated Data Communications technologies will support and enhance the Next Generation Air Transportation System (NextGen). Once implemented, Data Communications and NextGen will enable air traffic control to issue complex clearances to a pilot and the aircraft's flight management system via electronic data transfer instead of time consuming voice transmission.

Development and implementation of this transformational technology is important to achieve the benefits of NextGen. An overview of the planned path ("roadmap") for DataComm in the context of NextGen is illustrated in Figure 9, taken from the FAA NAS EA as of November, 2010. Between 2010 and about 2015, the FAA will build on the existing TDLS used to deliver pre-departure clearances and the Digital Air Terminal Information Service (D-ATIS) to the flight deck.

The NAS EA Communication Roadmap (Figure 9) indicates that implementation of DataComm Segment 1 (DataComm1) should begin about 2012. In the ATCT cab operating environment, DataComm1 "will implement data communications capabilities that will provide new methods for delivery of departure clearances, revisions, and taxi instructions." The first two capabilities – departure clearances and revisions – are extensions of current Tower Data Link Services (TDLS) capabilities. Issuing taxi instructions via digital messaging will be more complex. The message set for digital taxi instructions has not been defined (Wargo & D'Arcy, 2011). The Computer-Human Interface (CHI) for creating and issuing digital taxi instructions has yet to be defined. One implementation is found in the Tower Operations Digital Data System (TODDS; Truitt, 2006; Truitt & Muldoon, 2007, 2009, 2010).

However, voice-over-radio will remain the primary method for delivery of time- and safety-critical instructions in the mid-term, depending on aircraft equipage (Truitt & Muldoon, 2010; Wargo & D'Arcy). The Final Investment Decision for DataComm Segment 2 (DataComm2) is planned in 2015, according to the NAS EA (Decision Point 304 in the NAS EA), with an initial operating capability about 2019. For the purposes of this analysis, DataComm1 refers to capabilities expected by 2018, and DataComm2 refers to far-term capabilities (2019 and beyond). DataComm2 capabilities are excluded from this analysis.

Tower Cab DSTs

Tower cabs have the least automation of the three operational ATC environments, imposing a significant workload on the cab controllers. Significant investments have been made in research, engineering, and development to address operational shortfalls. The work on tower cab automation has been dominated by three technical approaches: 1) operations research; 2) integrated information displays; and 3) shared situational awareness. While there is conceptual overlap in the three approaches, they generally have been undertaken by relatively discrete and independent groups. The operations research approach has been dominated by researchers, academics, students, and organizations affiliated with the Massachusetts Institute of Technology (MIT). A key concept that emerged out of the operations research work is the notion of the Departure Planner (Anagnostakis, Idris, Clarke, Hansman, Odoni, & Hall, 2000; Feron et al., 1997). Integrated information displays have been the focus of FAA research (Truitt, 2005). The key concept from the display-centered research is the electronic representation of flight strips for the tower. The shared situational awareness line of inquiry is dominated by NASA and associated researchers. This line of research produced the Surface Movement System (SMS), which has undergone trials in simulations and at DFW, Memphis International (MEM), and Louisville Standiford (SDF) airports (Lockwood, Atkins, & Dorighi, 2002; Atkins, Walton, Arkind, Moertl, & Carniol, 2003; National Aeronautics & Space Administration, 1999a, 199b; Walton, Atkins, & Quinn, 2002).

In recent years, these three lines of research have coalesced around a set of five "capabilities" for the tower cab: 1) airport configuration; 2) departure routing; 3) runway assignment; 4) sequencing and scheduling; and 5) taxi routing. Each "capability" consists of a bundle of functional requirements. For example, the airport configuration capability encompasses four functions in the mid-term: airport planning information; stochastic analysis (of the impact of a proposed configuration on airport flow rates); coordination with the airport authority; and configuration advisories for multiple airports in a single metroplex (for example, DFW and Dallas Love (DAL)) (Morgan, 2010).

The Tower Flight Data Manager (TFDM; System 706 in the NAS EA; FAA, 2010f; Nene & Morgan, 2009) is intended to provide the automation platform on which these capabilities will be hosted. Conceptually, TFDM consists of an interface to data sources such as radars and the Enhanced Traffic Management System (ETMS), a Flight Data Manager (FDM), Surveillance Data Manager (SDM), and a suite of DSTs (Nene & Morgan, p. 1-2). TFDM will feature (user) configurable displays. Tower controllers will interact with the displays and DSTs through an as-yet unspecified computer-human interface (CHI). Prototypes of some display and DST concepts have been subject to limited HITL simulations, but overall, they are largely in the concept exploration and development phase of the FAA's acquisition cycle, with key investment

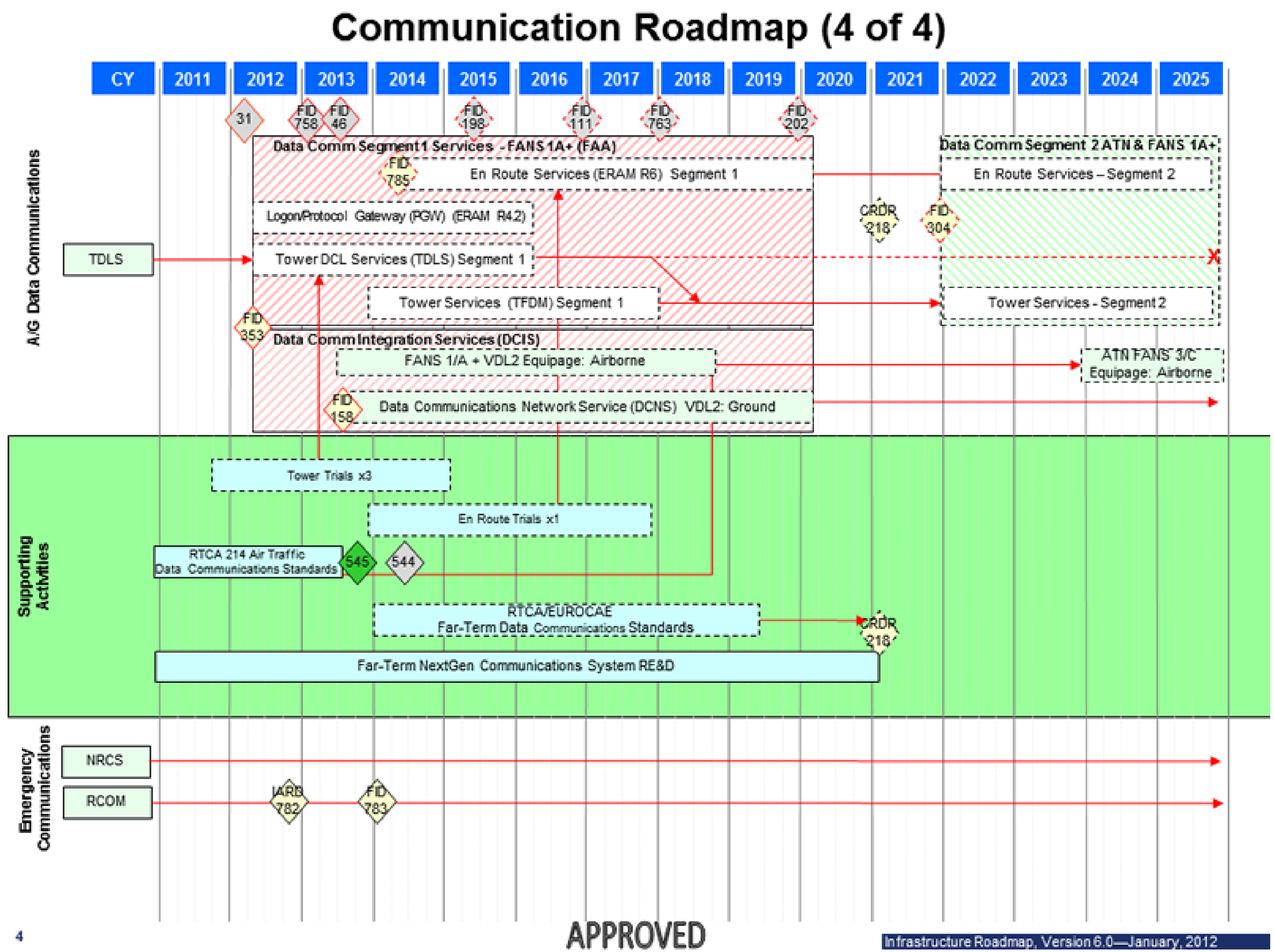

Figure 9: DataComm in the NAS EA Communication Roadmap (as of January, 2012)

decisions yet to be made. The TFDM acquisition program is in two phases. TFDM Phase 1 (TFDM1) will

> …integrate the Airport Resource Management Tool (ARMT), Tower Data Link Services (TDLS), Surface Movement Advisor (SMA), and Airport Movement Area Safety System (AMASS) functions. Terminal will determine through trade studies the means of integrating four additional legacy systems: Flight Data Input Output, Electronic Flight Strip Transfer System (EFSTS), Advanced Electronic Flight Strips (AEFS)/Electronic Flight Strips (EFS), and Departure Spacing Program/Departure Flow Management (DSP/DFM), the latter of which will reside as a new component (known as the Integrated Departure/Arrival Capability) in either TFDM or TFMS. (https://nasea.faa.gov/system/main/display/706)

TFDM Phase 2 (TFDM2) will deliver "Full Decision Support Tools (DST) with TDLS and SAIDS Integration" (https://nasea.faa.gov/decision/main/display/198/tab/detail). SAIDS (the Systems Atlanta Information Display System) is also known as the Integrated Display System (Version 4) and is installed at 390 facilities, including 25 of the 30 largest airports ("Core 30"; FAA, 2011).

TFDM1 and TFDM2 are depicted on the NAS EA Automation Roadmap (Figure 10). The Final Investment Decision for TFDM1 (as defined by the FAA's Acquisition Management System (AMS) (FAA, 2010c)) will not be made until late 2012 (Decision Point 115), with capabilities entering the NAS in the period between about 2013 and 2016 or 2017. A system schedule (e.g., describing actual delivery, installation, and commissioning at field facilities) is not available through the NAS EA. The Final Investment Decision for TFDM2 will not be made until 2014. The Final Investment Decision determines whether to move forward with a particular "investment opportunity" to "solution implementation" (AMS 2.4.4). The Automation Roadmap indicates that TFDM2 will span the period of about 2016 through 2019, that is, the mid-term focus of this analysis.

For purposes of this analysis, each proposed surface DST capability and its concept of use is briefly summarized. The working position most likely to use a given capability is identified. The use of these capabilities is then described, based on the available information such as NAS EA operational event threads ("OV-6c" scenarios) and simulations. The overall impact of the mid-term capabilities on cab controller functions, as described by Krokos et al in their 2007 update, is then assessed. Given an updated description of controller functions, aptitude requirements are then inferred from available information and compared to the baseline requirements.

Airport Configuration DST.[5] Airports have many discrete structural and operational elements, such as the familiar passenger terminal buildings, aircraft hangars, expanses of concrete around those buildings and hangars (known as aprons, ramps, and alleys), taxiways from terminals to runways, and runways. Just 17 (6%) of 262 FAA-towered airports have a single runway, 111 (42%) have two runways, 92 (35%) have three runways, and just 42 (16%) have four or more runways. A common configuration is two (nearly) parallel runways based on the prevailing winds; some have a third runway crossing the others at an angle. The tower, in cooperation with the airport authority, the aircraft operators (such as airlines), servicing TRACON, and traffic management, designates which runways and taxiways are to be used for various operations. Generally, this designation, or airport configuration, is largely based on past experience and practice, perhaps codified into a set of more-or-less "standard" configurations in routine use. Events such as a shift in wind, scheduled runway maintenance (to remove the rubber that builds up in the touchdown zone of a runway, for example), and unexpected closures of a runway or taxiway (due to a disabled aircraft, for example) might dictate a change from one configuration to another. At airports with a lower tempo of operations and simpler layouts, such a configuration might be relatively easy to implement. However, configuration changes at major hubs, with their streams of arrivals, departures, and taxiing aircraft, pose a significant challenge to the tower. The timing of a change can be especially important. Current tools available to supervisors include the Airport Resource Management Tool, fielded at 15 facilities (El-Sahragty, Burr, Nene, Newberger, & Olmos, 2004), and the Surface Movement Advisor (SMA) legacy system at 16 airports. However, most FAA towers have no automation or computerized support for assessing the merits of different configurations.

The Airport Configuration DST is intended to address this operational shortfall. The tools within this capability will provide assistance for setting up, assessing, and changing the configuration of an airport. The primary users of the Airport Configuration capability are the tower manager, tower supervisor on duty, and in larger facilities, the Traffic Management Coordinator; controllers at the Ground, Local, Clearance Delivery, and Flight Data positions are not intended to be users on a routine basis, except if serving as the Controller-in-Charge.[6] The mid-term concept of use for this capability includes scheduling the reconfiguration, optimization of the proposed configuration using stochastic analysis, and communication of the reconfiguration to users and stakeholders via data exchange (Dziepak, 2010; Morgan, 2010). The capability provides information on departure fix loadings, traffic management initiatives, and arrival/departure rates and future demand to the Tower Supervisor and/or the Traffic Management Coordinator (Sekhavat, 2009). The primary impact on tower cab controllers

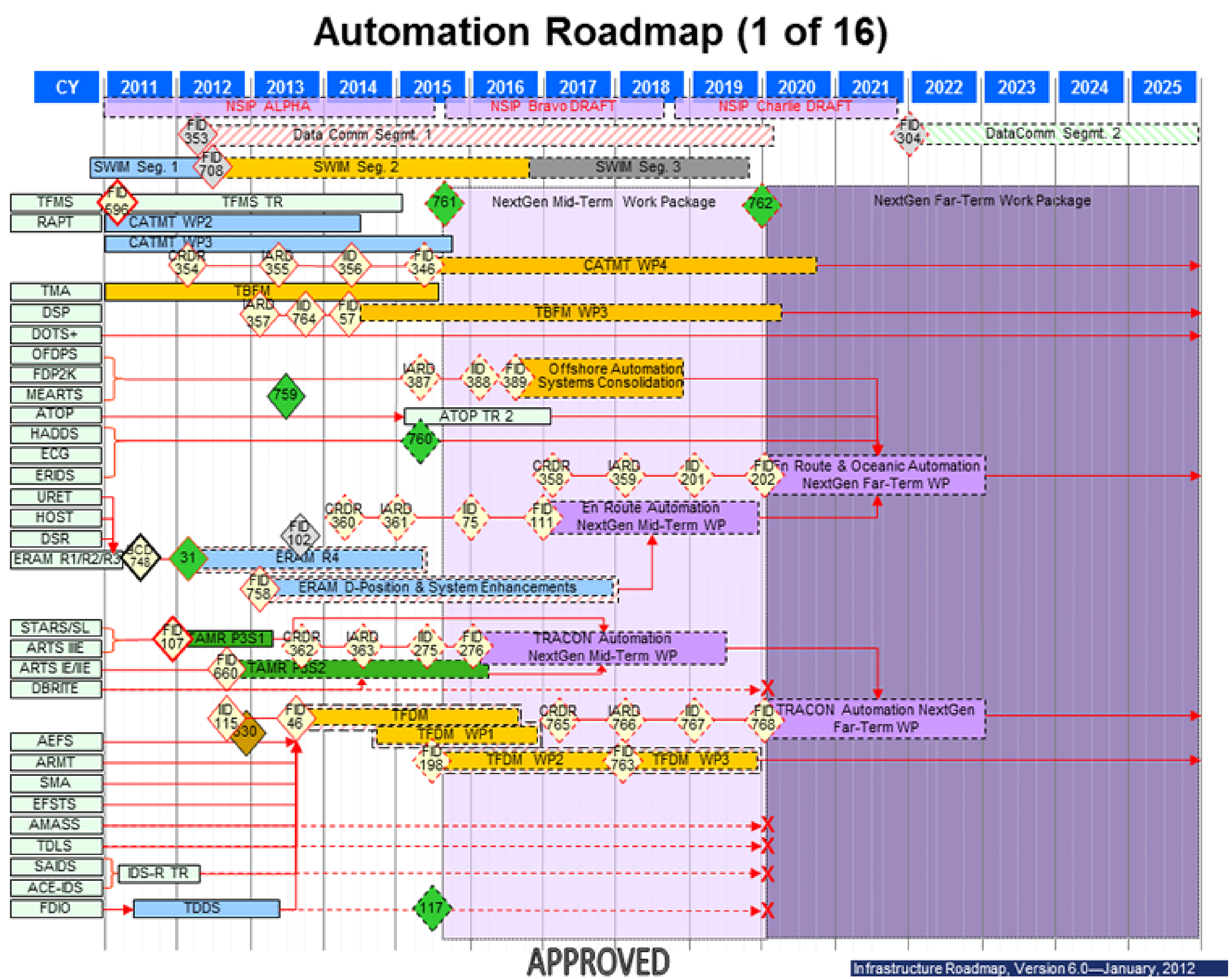

Figure 10: TFDM in NAS EA Automation Roadmap (January, 2012)

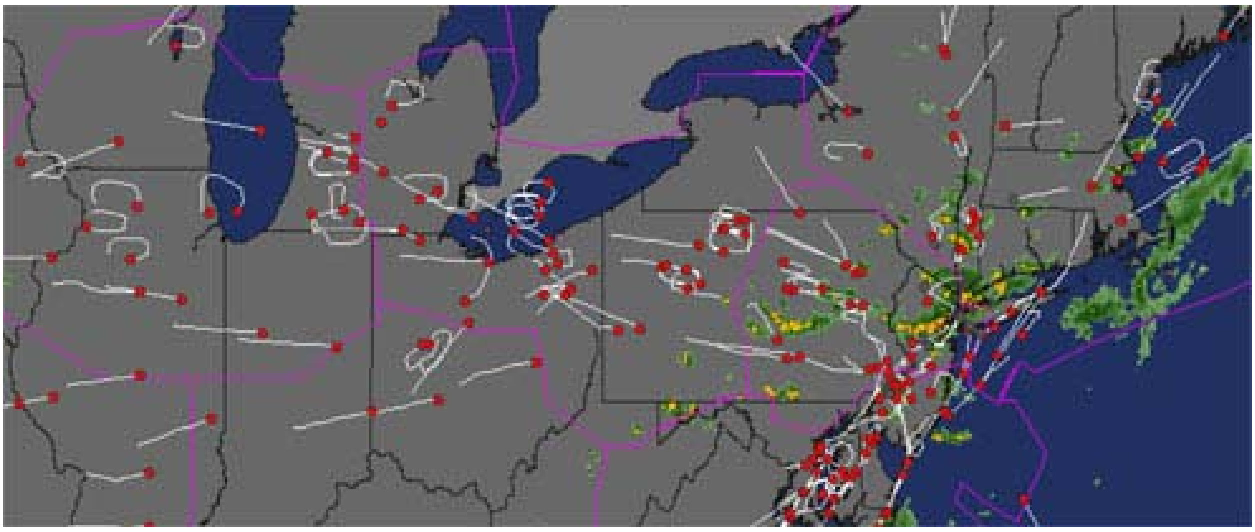

Figure 11: Illustration of air traffic routes from New York metro area (Source: MIT Lincoln Laboratory)

comes in executing the reconfiguration as directed by the supervisor. For example, Ground might need to issue a series of new taxi instructions to aircraft in the departure queue to direct them from the north to the south end of the departure runway because of a wind shift (from south to north, as sometimes happens at DFW with winter storm fronts). While there is clearly additional workload associated with a reconfiguration of the airport, the overall activities performed by controllers in the cab remain the same. Controllers will still scan their areas of responsibility on the airport surface, monitor movement on the surface, assess separation, manage sequences of departures and arrivals, issue control instructions, mark flight progress strips, and manage position resources. Therefore, the Airport Configuration capability has minimal impact on the duties, responsibilities and roles of the tower cab controllers. Their workload, however, is likely to temporarily increase during the actual execution of the configuration change.

Departure Routing DST. The *Departure Routing DST* provides flight-specific assessments of the availability of (filed) departure routes, given weather conditions and traffic flow constraints. For example, the frequently used departure routes out of the New York metropolitan area (from JFK, LGA, and EWR) for south- and west-bound aircraft are geographically concentrated (Figure 11). Convective (and other) weather systems can require greater spacing between aircraft on some routes. Weather can also close routes entirely. The *Departure Routing* capability integrates weather, traffic, and airspace information to assist air traffic managers and flight operators in making traffic flow management decisions (Kell, Masalonis, Stelzer, Wanke, DeLaura, & Robinson, 2010). The *Departure Routing* capability provides Traffic Management Coordinators and flight operators with the capability to answer questions such as "Where is the weather or congestion?" and "How will a traffic management initiative or re-route of specific flights avoid the weather or mitigate congestion?" (Jackson, 2010; see Figure 12).

The *Departure Routing DST* extends the basic functionality of the Route Availability Planning Tool (RAPT) currently in use by air route traffic control centers in the upper midwest and northeast, New York metropolitan area airports, the New York TRACON (N90), and several flight operators (Kell, et al.). *Departure Routing* will provide a graphical depiction of departure routes with an overlay of weather information. It provides tools to TMCs to identify intersections of routes and specific flights with adverse weather or congestion and to evaluate route alternatives (Sekhavat, 2009). The primary users of *Departure Routing* are Traffic Management Coordinators and flight operators. The primary impact on tower cab controllers will be in delivering route amendments to pilots to implement DST-generated solutions. Route amendments are an example of workload-intensive voice communications that might be supplanted by DataComm. But overall, *Departure Routing* does not change the activities, sub-activities, tasks, roles, and responsibilities of the tower cab controllers.

Runway Assignment DST. A key responsibility for Ground Control is the assignment of departures to runways. Tower procedures generally require designating which runway(s) will be used for departures, arrivals, and mixed operations. At simpler airports with one, two, and even three runways with lighter traffic, assignment of departures to a runway is a relatively simple decision. However, at large, complex and busy airports, runway assignment is complex and can have substantial consequences on the airport departure rate and departure delay. Ground must consider factors such as the destination, initial departure fix (marking the beginning of the intended route), number and types of aircraft in the queue for each active departure runway, route of flight, and operator preferences. For example, in the "South Flow" configuration of DFW

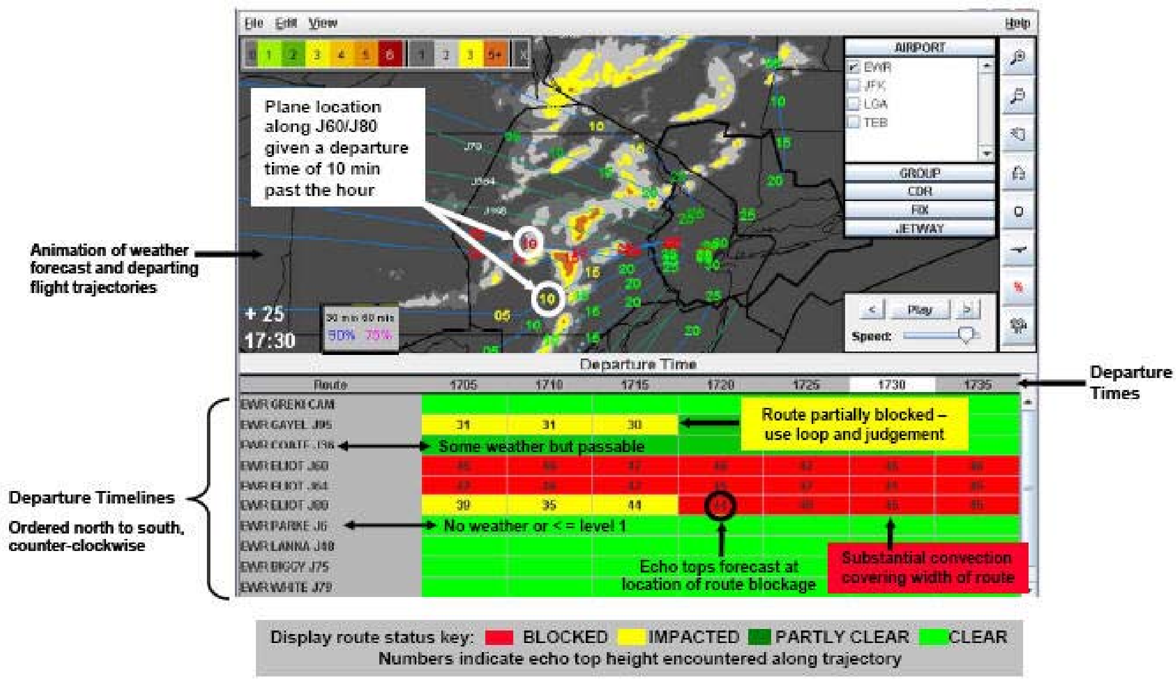

Figure 12: Overview of graphical interface for Route Availability Planning Tool (RAPT) (Source: MIT Lincoln Laboratory http://www.ll.mit.edu/mission/aviation/wxatmintegration/rapt.html)

(Figure 3), east-bound aircraft generally depart from 17R and 17L (and turn left on departure), while west-bound aircraft depart from 18L (and turn right on departure).

At present, departures are assigned to runways by Ground, based on codified procedures, rules-of-thumb, past practice, and ATCS experience and judgment. As a consequence, this manual process is characterized as resulting in inefficiencies in use of airport resources such as the runways, especially at times when demand exceeds the capacity (FAA, 2009b). Provision of a DST to assign aircraft to runways is one way to address this operational shortfall. The mid-term *Runway Assignment* capability will assign departures to runways based on rule sets, such as departure fixes and destinations for load balancing. Essentially, this capability computerizes existing Standard Operating Procedures and practices. By the mid-term, the *Runway Assignment* capability will also display any added delay cost for not using the recommended runway (Dziepak, 2010; Morgan, 2010), but responsibility for the actual assignment of an aircraft to a runway will reside with the controller as part of his or her responsibility for managing the departure queue and sequence. The controller can accept, modify, or ignore the recommended runway assignment appearing on the departure electronic flight strip (Figure 13).

The interface for assigning a runway has not been specified as yet. Current concepts are based on electronic flight strips arranged in bays on a touch-screen display, where the bays correspond to operational phases such as pending, departures, and arrivals (see Stelzer, 2010, Appendix D for an example, and Figure 14). The controller selects a strip by touch or mouse click. In the MITRE simulation, the selected strip "opens up" and the fields can be selected and edited. Runway assignment might be made via a drop-down list or direct data entry. However, these details have not yet been fully worked out and are still in concept development and exploration. The "peak departures" and "peak taxi demand" scenarios in the FAA EA OV-6c scenarios refer to runway assignment as part of the development of an "integrated and collaborative schedule" for airport operations.

Scheduling & Sequencing DST. The *Scheduling & Sequencing DST* proposed in the mid-term is intended to derive a schedule of departures, given traffic flow management constraints, runway assignments, aircraft readiness, and wake turbulence mitigation. There is no

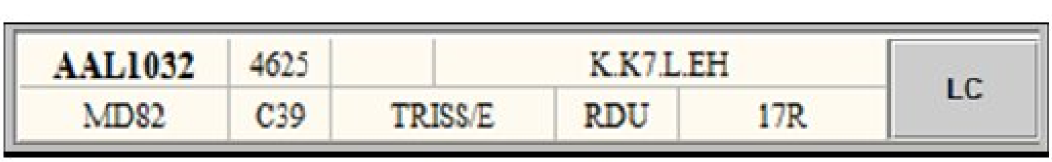

Figure 13: Example electronic flight strip for a departure assigned to Runway 17R (Source: MITRE CAASD MTR100188, p. 2-7)

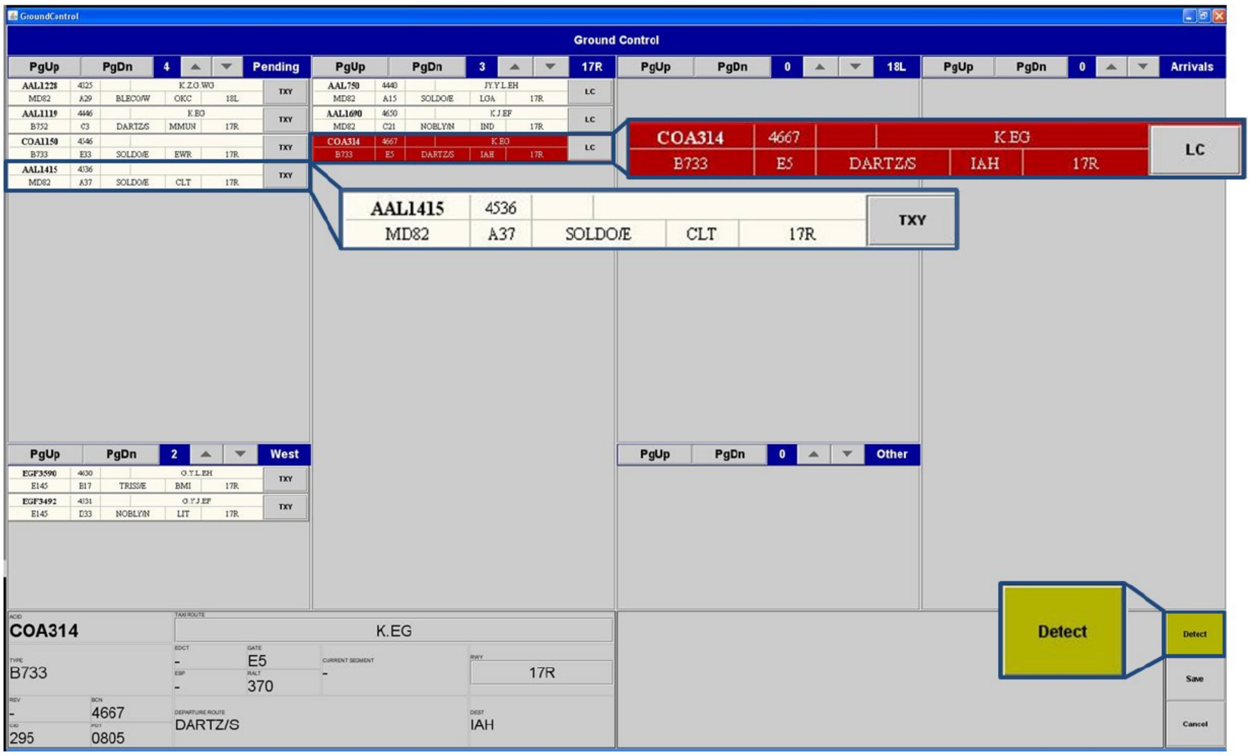

Figure 14: Electronic flight strip display used by MITRE in Conformance Monitoring human-in-the-loop simulation (Stelzer, 2010, p. 2-8)

automation support for the Ground controller at present to develop a schedule or sequence of aircraft; as a consequence, controllers work with the flights at hand in a very tactical approach, generally on a "First Come, First Served" basis in accordance with the FAA Air Traffic Control procedures order (specifically, Paragraph 2-1-4; FAA, 2010b). This strategy allows the Ground controller to provide surface control services in an equitable manner to the various classes of users. The *Scheduling & Sequencing DST* is intended to provide recommendations to Ground as to which aircraft to take next for taxi instructions. In the mid-term, the order of service might be determined by flight prioritization rules other than "First Come, First Served" (Joint Planning & Development Office, 2011).

For example, an aircraft with a Flight Management System that can receive and execute a digital taxi instruction (D-TAXI) might be given priority in the schedule over a similar aircraft without that capability. The better equipped aircraft would be sequenced ahead of the other aircraft in the departure queue. However, scheduling and sequencing algorithms are the subject of on-going research and modeling. A key problem in the development of surface scheduling and sequencing algorithms is the inherent uncertainty of surface operations (Brinton, Krozel, Capozzi, & Atkins, 2002a, b; Brinton & Atkins, 2008; Atkins, Brinton & Jung, 2008; Rapport, Yu, Griffin, & Daviau, 2009).

There are several sources of uncertainty in surface operations that will impact the stability and efficiency of the DST proposed solution. The first source is that not all aircraft are required to file a flight plan, so some are unknown to the automation system. Even a small airplane can technically fly from and to a major airport without a flight plan, provided the airplane has certain equipment, the pilot can afford the airport fees, and the flight is conducted under visual flight rules (VFR). As shown in Figure 15, the vast majority of operations at the 30 large "core" airports are conducted under Parts 121 and 135, most likely with filed Instrument Flight Rule (IFR) flight plans. For example, 99% of over 614,000 operations at DEN in 2009 were conducted under Parts 121 and 135 according to historical data from the FAA's Terminal Area Forecast (FAA, 2010h). These flights, with filed flight plans, would be taken into account by the *Scheduling and Sequencing DST*. Just 1% of operations at DEN were conducted under Part 91 or military regulations, representing over 3,800 operations a year, or roughly 100 a day. At least some of the Part 91 and military operations involved flights <u>without</u> flight plans. Thus, they would be unknown to the DST and would not be incorporated automatically into the computer-generated scheduling and sequencing solution. At other core airports, even larger proportions of operations were conducted under regulations other than Part 121 and 135 according to FAA terminal operations data. For example, about 18% of the 246,738 logged operations at Chicago Midway (MDW) involved flights operating under Part 91 or military regulations, averaging about 100 a day. Some number of these flights would have

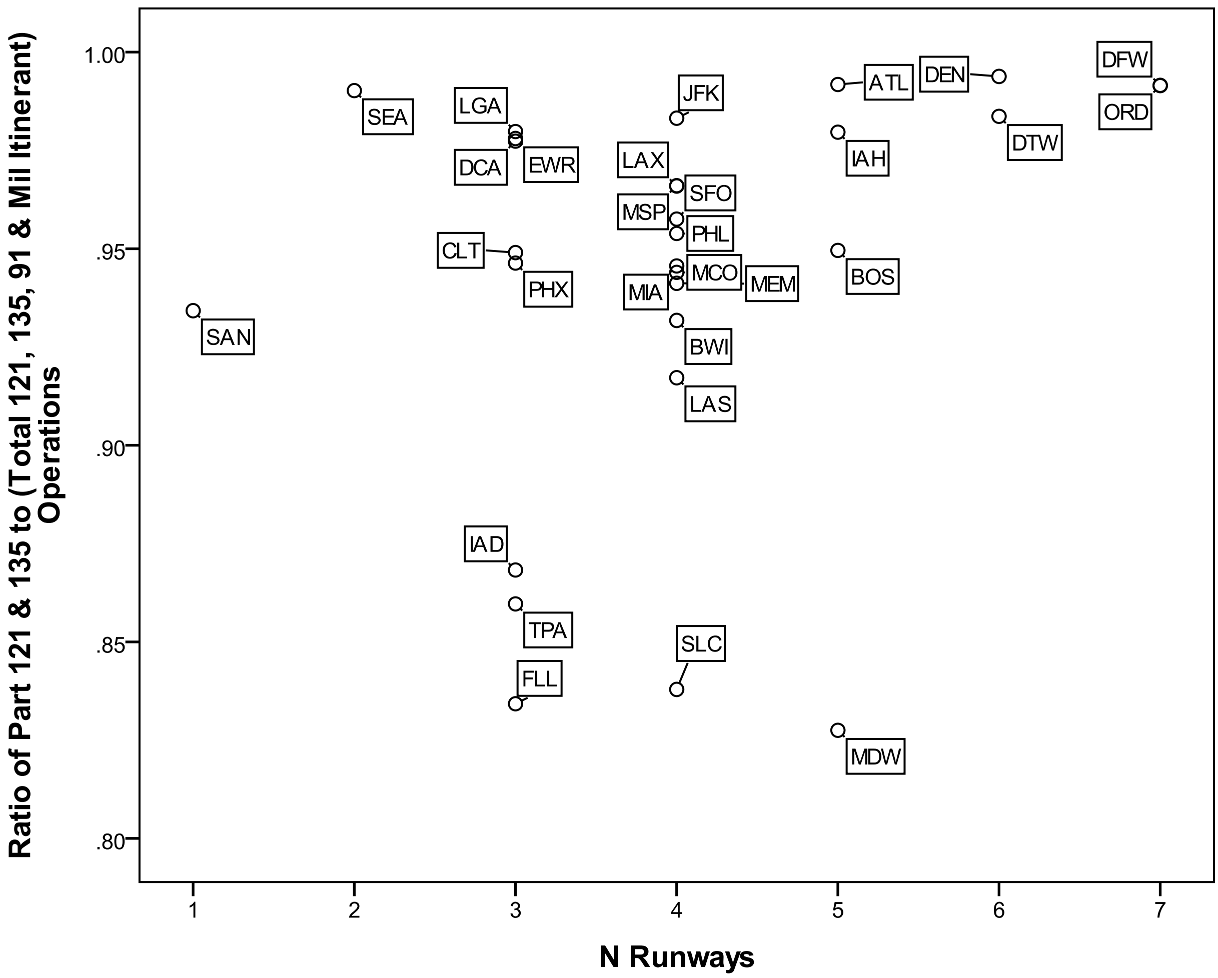

Figure 15: Ratio of Part 121 & 135 operations to total itinerant operations (Parts 121, 135, 91 & military) based on the 2009 Terminal Area Forecast (TAF)

to be made known to the *Scheduling and Sequencing DST* through an as-yet unspecified mechanism.

The tower controllers, on the other hand, can observe the flights directly and integrate them into operations. The second source of uncertainty that would impact scheduling and sequencing on the airport surface is variance in estimating gate turn time for air carrier flights (as noted in Figure 15, the majority of flights at the 30 core airports). The lower bound for the error in estimating turn-time is about five minutes; the average error is closer to 15 minutes (Carr, 2004).

Turn-time directly impacts gate availability and arrivals in the taxi-in phase of operations. Developing schedules and departure queues (sequences) that are robust to the uncertainty in turn-time is challenging (Carr). The third source of uncertainty in surface operations is in aircraft movement, engendered by two factors: the physics of aircraft movement; and pilot reaction time and control inputs in response to ATC instructions (Williams, Hooey, & Foyle, 2006). A Scheduling and Sequencing DST would need to be robust enough to accommodate at least these three sources of uncertainty or "noise" to avoid excessive re-planning (Carr).

Yet surface operations scheduling and sequencing algorithms developed to date assume deterministic (that is, known and fixed) push-back, call-up, taxi times, aircraft movement, and pilot reaction to instructions. For example, the NASA Spot Release Planner, a scheduling application, is characterized as a "deterministic optimization problem" (Jung, Hoang, Montoya, Gupta, Malik, & Tobias, 2010). The assumption of deterministic, known, or fixed times for different key events, particularly in departure taxi operations on the airport surface, leads to "…a brittle decision support capability that provides unstable modeling results due to small variations in inputs, and/or decision support recommendations that end up being much less efficient than planned due to these uncertainties" (Brinton & Atkins, 2008, p. 1).

Assuming that a stable and efficient solution can be developed by the Scheduling and Sequencing DST (for example, through a stochastic algorithm (Brinton & Atkins)), it will be presented to Ground Control as a

Figure 16: Example future electronic flight strip bay (left) and airport surface display (right) (photo courtesy of Todd Truitt, FAA Technical Center)

recommendation. Ground retains the overall responsibility for scheduling and sequencing aircraft onto the taxiways, and can accept, reject, or modify the recommendation (Dziepak, 2010; Morgan, 2010). The CHI for presentation of and action on the recommended schedule and sequence has not been positively defined for the mid-term. One approach might be through the electronic flight strips, in which the schedule and sequence are implicit in the ordering of the strips in the departure bay(s). In this approach, doing nothing to change the order of strips would constitute acceptance of the automation's recommendation, while moving a strip (through a "drag & drop" method, for example) would represent a modification. It is not clear how the controller would reject the DST recommendation. Overall, it is likely that a Scheduling and Sequencing DST will change the details of what the controller looks at in the cab on a display, but the function performed by the controller will not dramatically change in the mid-term with the introduction of a Scheduling and Sequencing DST.

Taxi Routing DST. In the mid-term, automation will also generate a recommended or advisory taxi route for a given aircraft, based on factors such as pre-established routes, congestion, and user preferences. The Ground controller can accept, reject, or modify the recommended taxi route via an (as yet) unspecified CHI. Trials of automated taxi routing ("D-TAXI") have been optimistic about the concept but cautious about the details of implementation, particularly with reference to the CHI and required local adaptations. The European Airport Movement Management by A-SGMCS Part 2 ("EMMA2;" Jakobi, Porris, Moller, Montebello, Scholte, Supino, et al., 2009; Teutsch, Scholte, Jakobi, Biella, Gilbert, Supino, et al., 2009) project simplified the CHI by integrating taxi routing with the electronic flight data display. TODDS (Truitt & Muldoon, 2010) takes a similar approach, as shown in Figure 16, as does the Surface Decision Support System (SDSS; McGarry & Kerns, 2010). However, a cautionary note was sounded with regard to automated taxi route generation (Jakobi et al., 2009):

> A highly sophisticated and responsive routing function, that is able to cope with all operational circumstances in order to provide the ATCO [air traffic controller] with the right taxi route, whenever called upon, is an absolute must to keep manual interaction to a minimum and to get the ATCOs acceptance to transmit taxi routes by TAXI-CPDLC (p. 17).

What constitutes a "highly sophisticated and response routing function" is the subject of continuing research and development. As with the Scheduling and Sequencing DST, solution stability, (physical) feasibility, and operational acceptability are important criteria. Moreover, air traffic procedures for the use of the taxi routing DST will be required, with modifications to the FAA Air Traffic Procedures order (FAA, 2010b) and the Airman's Information Manual (AIM). Procedural issues that must be addressed in parallel with development of the Taxi Routing DST include under what conditions Ground will (mandatory) and might (discretionary) accept the recommended taxi route, amend (modify) it, and reject it.

If Ground rejects the first proposed route, it is unclear if the system will generate another route or if the controller will be prompted to create an independent solution. In addition, some research suggests that a routing tool will re-plan about every 10 minutes as events play out on the surface and that re-computation of the taxi routes can take about two minutes (Balakrishnan & Jung, 2007). Re-planning might also be triggered when the controller rejects a proposed taxi route. The sensitivity to perturbations and time required for computation are being addressed in intensive research and modeling by organizations such as MITRE CAASD, Mosaic ATM, and METRON Aviation.

If, and only if, stable, achievable, and efficient routes can be generated by a "sophisticated and responsive" algorithm, what is left to the controller, particularly at the GC position? First while the taxi route might be uplinked directly to aircraft that are properly equipped, the actual instruction to move will still be issued by the human controller working Ground by voice (Morgan & Burr, 2009, p. 56). It is worth noting that not all aircraft calling the tower will be in the system with a filed flight plan and that some might file just before calling the tower for taxi instructions. The Air Traffic Procedures order requires the FAA to provide taxi and control instructions to all aircraft in the movement area. Since the Taxi Routing DST will not be aware of flights without a filed flight plan, it cannot generate a route for such flights. It is not clear how this operational fact will be solved. The most likely solution is manual controller intervention.

Moreover, because of the inherent stochastic (uncertain) nature of surface operations as noted previously, Ground will not be able to simply default to pressing the "Accept" or "Send" button for a proposed taxi route without at least some (quick) evaluation. The controller working Ground will have to assess the safety of a proposed taxi route in light of current and future conditions. Without the Taxi Routing DST, this evaluation is of the controller's own plan relative to current surface traffic and conditions. With the Taxi Routing DST, the evaluation is of the automation's proposed taxi route, to ensure that it is conflict-free and complies with any airport-specific constraints. The controller then issues the taxi instruction by selecting "Accept Taxi Route" (or its functional equivalent) and, presumably, DataComm transmits the instruction to the aircraft Flight Management System. Alternatively, Ground Control might say the taxi instruction over the radio if there are time and/or safety issues. Thus, the overall functions of the Ground in issuing taxi instructions does not change substantively; an additional data input as an advisory is presented, but the controller retains decision-making responsibility – and liability – for those decisions.

However, taxi Conformance Monitoring, a subset of the Taxi Routing DST capability, might have more impact on the Ground and Local controller than any of the other mid-term tower cab capabilities. As noted by Dziepak (2010) and McGarry and Kerns (2010), there are no alert systems for detecting taxi route deviations at present; the NAS relies on controller scanning of the airport surface to detect conformance problems. The Airport Movement Area Safety System (AMASS) is an add-on to ASDE-X. AMASS predicts collisions between tracked objects but does not monitor conformance to taxi instruction(s) (Northrop Grumman Norden Systems, Inc., Performance Technologies International, Inc., FAA Air Traffic Training (ATX-100), & FAA Academy Air Traffic Training Division (AMA-500), 2004).

The mid-term Conformance Monitoring capability might supplement controller perception. HITL simulation suggested that conformance monitoring was helpful to controllers in detecting pilot deviations: Controllers detected 100% of pilot deviations with conformance monitoring, and just 73% without monitoring (Diffenderfer & Morgan, 2010; McGarry & Kerns, 2010; Stelzer, 2010). The research on the speed with which a controller detects a deviation with and without conformance monitoring is equivocal. In one HITL simulation, the controllers were no faster in detecting deviations with than without conformance monitoring (Stelzer). In the second HITL simulation, the controllers were faster (McGarry & Kerns). Both simulations demonstrated that there are significant issues in determining how much of a deviation will trigger an alert, particularly for "hold short" instructions. The Conformance Monitoring capability relies upon the existence of a flight plan with current trajectory and intent (taxi instruction) data. Such data would be unavailable for aircraft without filed flight plans in the system, and the cab controllers would be required to monitor those aircraft in much the same way as today. Moreover, keeping the system updated with current intent data, particularly if Ground modifies a taxi instruction, could increase controller workload, offsetting any reductions gained

through use of the Conformance Monitoring capability (McGarry & Kerns). Overall, the mid-term Conformance Monitoring might be a supplement to human perception in 2018. But it is likely that controllers will still have to scan the airport movement area and runways. Therefore, the functions of monitoring the ground situation and controlling aircraft movement remain the controllers' responsibility in the mid-term.

ATCT Cab Workflow in 2018

The workflow within the ATCT cab in the mid-term timeframe is described next. This provides the basis for comparing and contrasting mid-term to current controller behavior. First, the activities required of the tower cab controllers in handling a single IFR Part 121 nominal departure with a filed flight plan are described. The description is based on two sources: (1) the OV-6c scenarios for peak taxi and peak departures in the NAS EA (FAA, 2010f); and (2) concepts of operations and use delivered by the MITRE Center for Advanced Aviation Systems Development (CAASD) (Nene & Morgan, 2009; Sekhavat, 2009; Morgan & Burr, 2009). This section closes with brief discussion of multiple operations, mixed equipage, and changes in the operating paradigm for the mid-term.

Nominal Departure

Standard or "canned" flight plans for IFR Part 121 departures are often filed months in advance with the FAA, and are activated by the AOC (also referred to as the Flight Operations Center (FOC)). The airline activates the flight plan at some point before the scheduled departure time via FAA-AOC automation. Traffic flow management automation then "works" the flight plan based on user preferences, weather, traffic, and other constraints that might apply to the specific flight. While details are not available as yet, at some point before the scheduled or planned departure time, the flight operator updates the Flight Data Object, the repository for the data for that specific flight, with the estimated departure time and departure gate (Morgan & Burr, 2009). The surface automation takes (receives) the Flight Data Object and develops a proposed sequence and schedule for the departure and, possibly, runway assignment and taxi routing, taking into account the airport configuration, traffic management initiatives, weather, congestion, and other factors. The flight plan is dynamic and is updated before the scheduled departure to reflect new data, weather conditions, and traffic constraints. The Scheduling and Sequencing DST builds an "integrated collaborative schedule" (Morgan & Burr, p. 48 & 52) for departing aircraft, including this specific flight. In parallel, the Runway Assignment DST tentatively allocates the flight to a departure runway based on procedures, constraints, and congestion. Given the expected departure runway, airport configuration, and the "integrated collaborative schedule," the Taxi Routing DST identifies the set of predefined taxi routes applicable to the flight (for convenience, flight ABC432). The proposed solutions developed by the DSTs are updated as the surface traffic situation evolves over time. At this point, nothing for this particular flight (ABC432) is displayed to the controllers working the Ground or Local control positions in the tower cab.

About an hour before the scheduled departure time, the airline updates the system with new or changed information, such as a gate change or a slip in the planned departure time for ABC432. The surface automation updates the sequence and schedule, runway assignment, and taxi route in response. At this point, the flight information is available to the supervisor, tower Traffic Management Coordinator (if staffed), and to the flight operator. The flight operator's Ramp Control might use the Collaborative Departure Queue Manager (CDQM; Brinton, Lent & Provan, 2010; Diffenderfer, 2010) to determine the time and sequence for push-back of different flights, including the present one, based on the operator's procedures, priorities, preferences and the scheduled "spot time" for the flight. Some electronic negotiation with the FAA might be required through CDQM or other external data interface.

Anywhere from an hour to perhaps 15 to 20 minutes before the scheduled departure time, depending on local practices, the controller working Flight Data or Clearance Delivery positions (or the combined positions) in the cab requests the flight plan for ABC432 via the cab controller workstation. Alternatively, the data for the specific flight might be "pushed" to the FAA Flight Data and Clearance Delivery positions and to the operator Ramp Control (Audenaerd, Burr, Diffenderfer, & Morgan, 2010). The FAA Flight Data and/or Clearance Delivery controllers and operator Ramp Controller review the flight data, presented as an electronic flight strip. Any changes in the route of flight (the "4D trajectory" in NextGen), due to information not known to the system or other local reasons, are made by the Flight Data/Clearance Delivery controller via an as-yet unspecified workstation CHI. Then Flight Data/Clearance Delivery issues the departure clearance via DataComm (assuming the aircraft is properly equipped) (Step 4, Scenario 7 "Peak Departures," OV-6c dated December 2010). The departure clearance includes the route of flight and clearance limit for ABC432, any restrictions, and other required or pertinent information. The interface used by the Flight Data/Clearance Delivery controller in the mid-term might be similar to the current TDLS interface under DataComm1. The aircraft acknowledges the departure clearance transmission; if acceptable, a "WILCO" (Will Comply) digital message is sent to the Flight Data/Clearance Delivery position. The surface automation uses this exchange to update the

flight data for ABC432 with a "(departure) clearance delivered" message; this action transfers the flight plan for ABC432 to the Ground Control's "pending departure list" (Audenaerd et al., p. 4-7). The aircraft is still at the departure gate when the DCL is sent by the FAA and acknowledged by the pilot.

Once "buttoned up," the aircraft calls the company Ramp Control for push-back from the departure gate in accordance with the "integrated collaborative schedule," Ramp Control has access to the departure clearance, the required spot time, and runway assignment via external data exchange. The Ramp Control instructs flight ABC432 to push back from the gate and taxi to the designated "spot." Ramp Control enters the actual push-back time for ABC432; that time is propagated through the external data exchange to the FAA automation, and the Flight Data Object is updated, including expected runway assignment and proposed taxi route. In the mid-term, this preliminary taxi route constitutes the initial 2-dimensional (2-D) surface trajectory to be used by the Conformance Monitoring capability.

As noted above, ABC432 is now in the Ground Control's "pending departure list." The exact manner of presentation or display for the "pending departure list" has not been specified. However, it is seems likely that it will consist of an array of electronic flight strips. The sequence and schedule of departures might be implicit within the ordering of strips. The electronic flight strip arrays might also be split by departure runway and perhaps taxiway or taxi route, as well as status ("pending" versus "active"). Screen shots in reports and briefings all suggest layouts of strip bays that reflect the physical queues and runways. The electronic flight strip display used by MITRE in a human-in-the-loop simulation is illustrated in Figure 17 (Nene & Morgan, 2009). In that study, controllers interacted with strips through a touch screen and keyboard; voice recognition is an unlikely technical possibility, given the accuracy required and time constraints. It might be the case that failure to re-order the sequence of strips constitutes (passive) acceptance of the automation's solution. In any case, the controller working the Ground Control position reviews the proposed sequence and schedule as presented

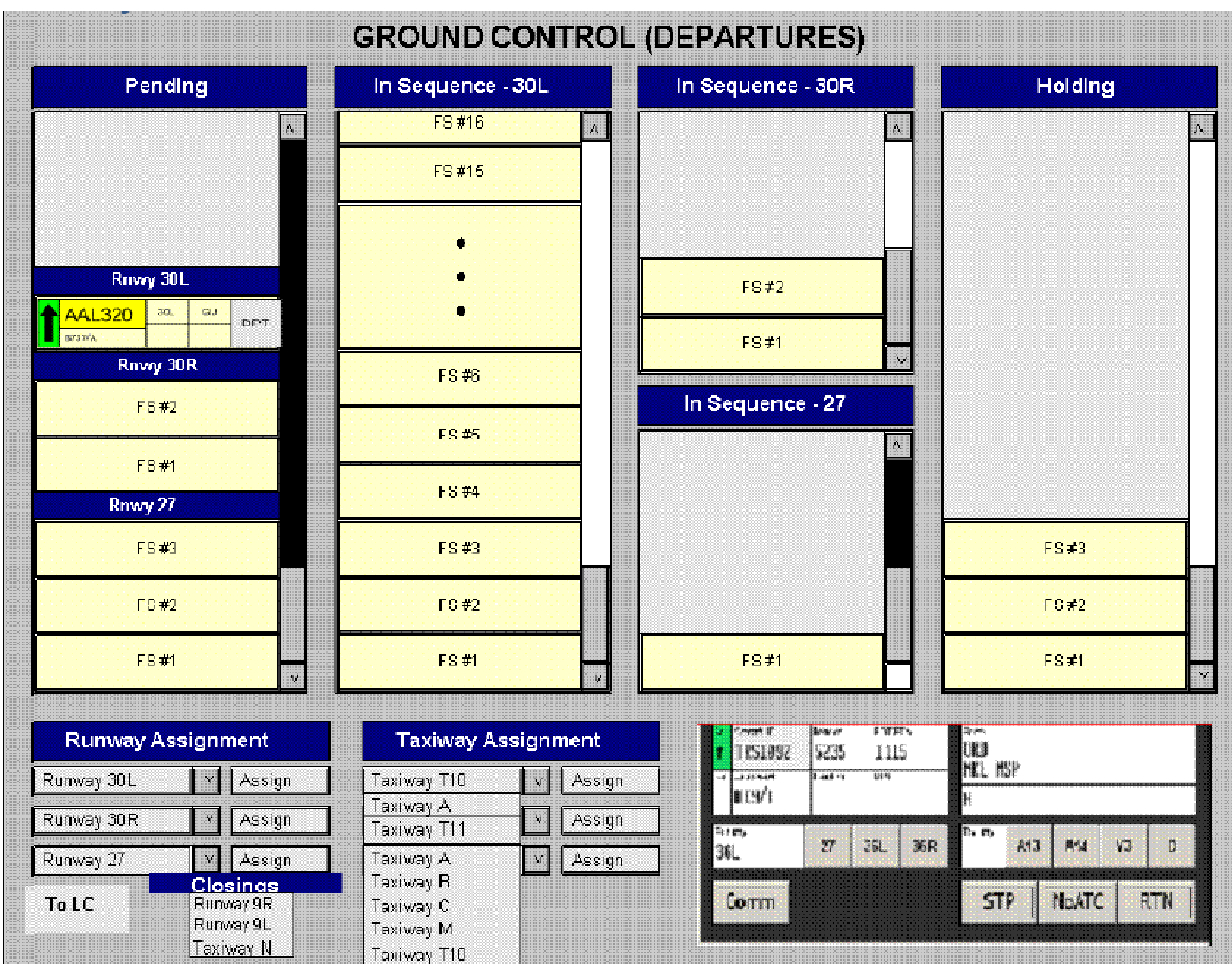

Figure 17: Example possible configuration of departures flight data display (Source: Nene & Morgan, 2009, p. 5-5 (Figure 5-3, Credited to William Hall, FAA))

in the array of strips. However, the criteria by which the proposed sequence and schedule of "pending" departures will be evaluated by the controller are not described.

Flight ABC432 taxis to the designated "spot," arriving at the required time, and calls Ground on the designated frequency: "ZYX ground, ABC432 at spot #, Ready for taxi." The most current concept of use indicates that in response, the Ground Control "updates" the "system" to indicate that the aircraft is in active taxi status. The method by which Ground updates the system has not been explicitly described. Whether it will be something like dragging an electronic flight strip from the "pending departure list" to the appropriate queue or highlighting the strip and pressing a physical or virtual "Accept" or "In Taxi" button, the key point is that an affirmative interaction with the "system" is required of the Ground Control. Additional controller actions might be required if the acknowledgment and taxi instruction are given via DataComm; what those actions are will depend on how DataComm is implemented. Potentially, multiple discrete physical interactions with a display could be required of Ground for a departure, in addition to any scanning of visual displays and of the airport surface.

The next step in the departure sequence is to issue the actual taxi instruction to the aircraft via DataComm or voice (Step 5, Scenario 7 "Peak Departures," OV-6c dated December, 2010). The proposed taxi route (generated by the Taxi Routing DST) will be displayed to Ground; the controller has the option to accept the proposed route, modify it, or reject it and issue a different route entirely. The controller might specify an ad hoc route by joining segments of pre-defined routes. The specific means by which the proposed routing is displayed to Ground has yet to be specified. One approach might be to display the proposed route graphically, as an overlay on the "bird's-eye" or plan view of the airport, when the aircraft call from the "spot" is acknowledged. Ground could manipulate line segments, for example, to modify a proposed taxi route (see McGarry &Kerns, 2010, Figure 2-9, p. 2-9). Alternatively, a text-based interface might be used, in which the controller types in alphanumeric strings representing intersections, taxiways, and hold short points, by editing the electronic flight strip. Both methods might be available to Ground.

In the Conformance Monitoring HITL simulation (Stelzer, 2010), the taxi route was printed in an area corresponding to Block 9b of the standard paper flight strip for a departure. As shown in Figure 12, the taxi route for American 1032 was K.K7.L.EH, read as "Taxiway Kilo to intersection Kilo seven, then taxiway Lima to intersection Echo Hotel." The last intersection is with the assigned departure runway, 17 Right (the innermost runway on the east side of DFW), at the north end of the runway. In the MITRE simulation, this was a standard taxi route named "Outer." In the MITRE simulation, doing nothing with a strip appears to have implied acceptance when automation generated the route. Ground could modify the route by selecting the strip by touch or by mouse-click. Then an editing screen opened through which the controller could type in a taxi route such as "K.K8.L.EH." Given passive acceptance of the proposed route or entry of an alternate route (by text or graphically), the actual taxi instruction is then issued to the aircraft. It is unclear what the interface and procedural steps will be to issue a taxi instruction via DataComm. Voice instructions are the norm today and will be optional in the mid-term (Step 5, Scenario 7 "Peak Departures," OV-6c dated December 2010). Regardless of how the taxi route for ABC432 is generated and issued to the pilot, the "automation system" is made aware of the intended taxi route to enable conformance monitoring on the airport surface.

After acknowledging the taxi instruction, ABC432 begins moving from the spot onto the assigned taxiway. The Conformance Monitoring capability compares current aircraft position to the expected route. If an aircraft deviates from the expected taxi route, current concepts of operation and use for conformance monitoring indicate that a auditory alert is sounded and the flight strip for the deviating aircraft is illuminated in red (Stelzer, 2010; McGarry & Kerns, 2010). In this example, flight ABC432 taxis, as instructed, uneventfully towards the departure runway. At some point, depending on local procedures, Ground instructs (by voice or DataComm) the pilot to contact Local Control on the designated frequency, and the aircraft is handed off to the Local controller "for take-off procedures" (Step 5, Scenario 7 "Peak Departures," OV-6c dated December 2010). As shown in Figure 12, this might be accomplished electronically by clicking or pressing the "LC" virtual button in the far right end of the electronic flight strip.

Local acknowledges the call from ABC432 and issues a "line up and wait" instruction to the flight in this simple scenario. The pilot taxis onto the departure runway, lines up on the runway centerline, and waits for the take off clearance. After visually scanning the departure runway to make sure it is clear, Local clears ABC432 for take-off. As the "line up and wait" instruction and take-off clearance are time and safety-sensitive, it is likely that these instructions will be issued by voice rather than DataComm in the mid-term. Moreover, absent a convincing demonstration that the surface and airspace situation displays are equivalent to visual operations and a corresponding change in ATC procedures, Local will still need to visually scan the departure runway by looking out the window, issue the take-off clearance, and instruct the pilot to contact TRACON. To complete this simple illustration, ABC432

takes off and then flies a published Standard Instrument Departure (SID). As ABC432 leaves the ground, its ADS-B (Out) signal is detected and processed by TRACON surveillance. The pilot switches to the TRACON departure control frequency in accordance with the published SID or as instructed by Local. The Local controller indicates that the aircraft has departed through an interaction with the flight data display. For example, Local might highlight the strip for ABC432 on the display and select a virtual "DEPARTED" on-screen button. From the perspective of Ground Control and Local Control, ABC432 is history and their attention turns to other events.

Nominal Arrival

In parallel to this departure operation, other flights are coming into the airport airspace and landing. For convenience, flight XYZ987 is arriving at the airport on a runway parallel to and outboard of the departure runway in the preceding nominal departure scenario. There is a taxiway between the two runways, and another taxiway inboard of the departure runway. The inboard taxiway connects with the operator's ramp and gates. Traffic flow management automation exchanges data for the in-bound flight with the surface automation. The expected landing runway is identified and given a gate assignment from the operator, the Taxi Routing DST generates a proposed 2-D inbound taxi route (Audenaerd et al, p. 4-5), and the surface model is updated. The surface automation receives final verification of the landing runway from the servicing TRACON automation as XYZ987 joins the final approach on a Standard Terminal Arrival Route (STAR). The inbound taxi route is finalized and uplinked to the Flight Management System from the surface automation via DataComm. The aircraft is instructed to join the parallel taxiway on runway exit; a specific runway high-speed turnout is not specified. A "hold short" of the parallel departure runway is included in the taxi instruction.

In accordance with the published arrival procedure, flight XYZ987 calls the tower on the Local arrival frequency for clearance to land. After acknowledging the call, Local visually scans the arrival runway and then clears XYZ987 to land. In Audenaerd et al.'s description, the surface automation "anticipates" which turnout will be taken based on aircraft deceleration and updates the taxi route based on the actual turnout taken and initiates Conformance Monitoring. At some airports (DFW, for example), Local clears the flight across the parallel (departure) runway in accordance with established local procedures and instructs the pilot to contact Ground. At other airports, Local hands off the arrival as it exits the runway and Ground coordinates the crossing of the inboard departure runway. Ground observes the flight as it progresses along the inboard taxiway to the transfer spot and notifies the operator Ramp Control that XYZ987 is released to their control. Conformance Monitoring is automatically terminated as the aircraft transitions from the taxiway to the ramp area. Ramp Control notifies the surface automation when XYZ987 is at the gate.

Multiple Operations

The nominal scenarios described by the concepts of operation and use for TFDM and associated surface DSTs are based on single aircraft examples. However, the cab rarely handles just one aircraft in any given phase of the operation. At almost any time of day at large airports such as DFW and ATL, the tower cab team is responsible for several aircraft, particularly when departure and arrival banks of flights overlap. Both Local and Ground are managing queues of aircraft, with a series of discrete actions required for each aircraft. Some of these actions will be aided by automation in the mid-term, for example, taxi routing. However, cab controllers are very likely to retain overall responsibility for the safety of the arrivals and departures. The tools used will change, and greater interaction with displays will be required of the controllers.

Mixed Equipage

It is not clear, at this point, what proportion of the fleet will be equipped for DataComm and ADS-B (Out) by 2018. The level of equipage might vary between and within operators. For cab controllers, the major questions will be (a) how to know which aircraft have what capabilities, and (b) what procedures to use with which aircraft, given an indication of their capabilities. For example, Truitt and Muldoon (2010) incorporated a triangular symbol into the aircraft data block to indicate data link capability in their DataComm Segment 2 HITL simulation of ground operations. However, national air traffic technical procedures for aircraft with and without DataComm have not yet been published. Procedures for use of air traffic control DSTs are dependent on the specific design and implementation of a given capability. The definition and publication of procedures for use of a DST can be lengthy. For example, the User Request Evaluation Tool (URET) was initially fielded in the mid-1990s under the "Free Flight Phase 1" program umbrella. However, rules for using URET were only recently incorporated into the national air traffic procedures order (FAA, 2010b). Development and vetting of procedures for handling aircraft with different levels of equipage will likely take several years and implementation in the mid-term will be a challenge for the air traffic control procedures community.

Change in Operational Priority

Another mid-term consideration is a change from the established equitable operational priority of "First

Come, First Served" to a different flight prioritization model (Joint Planning & Development Office, 2011). An early flight prioritization model was labeled "Best Equipped, First Served" (Department of Transportation Office of the Inspector General, 2009, p. 12; FAA, 2009b, p. 27). The model is straightforward: At any given time or in any given operation, the aircraft that has the "best" equipment profile will be given priority over a lesser-equipped aircraft, barring other operational or safety considerations. This operating concept is linked directly to the procedures for handling aircraft with mixed equipage as discussed above. Since 2009, a range of alternative flight prioritization models have been proposed (Joint Planning & Development Office, 2011); no single model has been adopted as yet. That being said, the impact of a change in operating paradigm will be different across positions within the tower cab. The sequence of aircraft to be handled by Local is determined by other positions. For example, the sequence of arrival aircraft will largely be determined by the servicing TRACON; Local will literally be taking the arrival stream "First Come, First Served" as hand-offs from the TRACON. Theoretically, the arrival sequence will have been optimized by the Traffic Flow Management automation and the surface automation's Scheduling and Sequencing DST. Changing the sequence of aircraft on final approach with a landing clearance would be an exception. For example, Local might issue a "Go Around" instruction to an arrival on final because of a pilot deviation onto the active arrival runway (e.g., runway incursion). Similarly, which departure will be taken next by Local will be largely determined by the sequence of aircraft setup by Ground Control, with the aid of the Sequencing and Scheduling DST in the form of the single, "integrated collaborative schedule." For example, the Sequencing and Scheduling DST could provide the Ground with a list of which departure to take first, second, and so on from the ramp, using equipage as a factor, along with taxiway loading, runway balancing, and wake mitigation rules. If the Traffic Flow Management automation and cab DSTs work as described, then the best equipped (or better performing) aircraft will likely have precedence over less well equipped (or performing) aircraft. The rub will come with exceptions, aircraft not known to the system, and unexpected (stochastic) events that create "off-nominal" situations. Since these types of events are unknown and/or unexpected, the cab controllers will likely have to adapt to the circumstances, with safety of operations being far more important than aircraft equipage in determining what action to take next.

Mid-Term ATCTs

Finally, the surface-oriented automation is targeted at the 30 largest U.S. airports. Some mid-size airports might also acquire these tools; a detailed waterfall schedule has yet to be made available. It is unclear what surface automation tools will be implemented at the other 200+ air traffic control towers staffed by the FAA by 2018. It is also not clear how the proposed DSTs, especially the Scheduling and Sequencing and Taxi Routing (with Conformance Monitoring) DSTs, could be used at airports with significant General Aviation (GA) operations conducted under VFR without filed flight plans. Example airports are Van Nuys (VNY) and Tulsa Riverside (RVS), both of which are among the 50-busiest towers in the country (FAA, 2010d). The current concepts of operation, concepts of use, Enterprise Architecture artifacts, and research and development reports are focused on solutions for the problems of large, busy hub airports.

About 20% of current terminal controllers (and their supervisors) work in the 30 largest core airports, based on September 2010 FAA employment data from the FAA Personnel and Payroll System provided to CAMI. About 25% of current terminal controllers (and supervisors) worked in stand-alone TRACONs (or Combined Center-Approach facilities such as Honolulu and San Juan, PR). The majority, however – more than 5,000 controllers and first-level supervisors – worked at 200+ mid-size and smaller airports. It is more likely than not that the tools and procedures used in these towers in 2018 will be similar to the ones in current use. Some mid-term automation, primarily those relating to traffic flow management, might be used by the Tower Supervisor in towers at mid-size and smaller airports. Some of these towers might be contracted out by 2018. It is also possible that some might be combined into Staffed NextGen Towers (SNTs), if the safety, cost, technological, political, and public risk perception concerns can be addressed in the next few years. A key technical issue will be certifying systems such as closed circuit TV for visually monitoring runways and taxiways as equivalent to visual operations. Finally, a "business case" for extending surface automation down to mid-size and smaller airports would have to be made for both the FAA and users. In view of these considerations, it seems more likely than not that that a significant number of FAA controllers –probably a majority of terminal controllers – will be working in 2018 in a tower cab environment more similar to today's working environment than the DST-centered environment envisioned for the mid-term at the 30 Core airports.

ANALYSIS OF MID-TERM NEXTGEN IMPACT ON APTITUDES REQUIRED IN THE ATCT CAB

Mid-Term DST Impact on Tower Cab Controller Roles & Responsibilities

Overall, the proposed DST capabilities will provide an electronic representation of flight data (as electronic flight strips, airport maps with tracks and associated flight data tags, and airspace map with targets and tags) and display recommendations for key tasks such as runway assignment, sequencing and scheduling, taxi routing, and conformance monitoring. Controllers will interact with these tools via unspecified (as yet) CHIs hosted on the TFDM platform. However, the controllers will remain responsible overall for the major job functions they currently perform such as monitoring the airport movement area, detecting problems, resolving conflicts and deviations, managing sequences of aircraft, and managing tower resources. The automation capabilities supplement rather than supplant human perception. Therefore, controllers are likely to continue relying upon their own perceptions and judgments, perhaps looking to the automation to confirm a course of action in the mid-term. How to perform those actions and use the automation (e.g., knowledge and skill) is a matter of training, not selection (under current FAA policy).

Mid-Term TOWER DST Impact on Aptitude

Given that the overall functions to be performed by human controllers are unlikely to change by the mid-term, then the profile of aptitudes required to perform those functions is likely to be very nearly the same. This is certainly the case for 200+ airports with FAA towers that are not slated to receive many (if any) of the NextGen DST capabilities by the mid-term – and the 5,000+ controllers working in those towers. The aptitude requirements for selection into these towers, representing about a third of the overall controller workforce, are unlikely to change as a consequence.

However, the larger, more complex towers associated with the 30 largest (and perhaps some of the mid-size airports) are slated to have at least some of the proposed DSTs installed and functional in the mid-term. Specific DST capabilities (depending on their actual implementation) and increased operations might make some aptitudes more important and others less so to successful performance of the job at these towers.

The heuristic input-process-output model (Figure 7) is used to organize the description of the aptitudes likely to be required of controllers at these larger, busy towers in 2018 (Table 4). The degree to which the importance of any given set of innate aptitudes increases or decreases depends heavily on the assumptions one makes with respect to the reliability of the proposed DSTs, the operational acceptability and stability of their solutions, and the likelihood of "Black Swan" (extremely rare but potentially catastrophic) off-nominal events. For this analysis, the perspective taken is that the DSTs will be reliable, produce stable, operationally acceptable solutions, and that off-nominal events such as equipment failure and loss of connectivity will be truly rare. Learned ATC-specific knowledge and skill will be more relevant to coping with such off-nominal events than aptitude per se.

In terms of input-related aptitudes, the requirement for (visual) Scanning will increase as the number and complexity of displays increase in the mid-term tower at large airports. Scanning the airport movement area out-the-window might be supplemented, or less likely, supplanted by scanning multiple large integrated displays. This shift from out-the-window to high-resolution displays will increase the need for controllers to apprehend and interpret symbols and other information on those displays. The worker requirements, Interpreting Information and Translating Information from displays, are likely to become more important to successful job performance in the 2018 cab. At the same time, the sheer volume of "data" presented to the controller via the DSTs and their displays will increase. For example, the timeline display suggested by Jung and colleagues (Jung et al, 2010) uses sequence, alphanumerics, highlighting, and color to represent a departure sequence. There simply will be more data points to be apprehended across fewer displays in the tower cab at large airports. Controllers will need fast and efficient heuristics to apprehend, organize, and assess displayed data. This aptitude was labeled Chunking in the 1995 analysis. With the volume of data and operations, the importance of Perceptual Speed and Accuracy to successful job performance is likely to increase in the mid-term as well.

The "chunked" information gained by the controller through scanning of the displays goes into Short-term Memory (STM); STM will continue to be a key aptitude through the mid-term. Greater demands will be made on Long-term Memory as controllers in the mid-term will have to memorize how to interact with the CHI for the cab DSTs under different circumstances or scenarios in addition to airport layout and the many air traffic control procedures (rules). The need for Sustained Attention will increase in the mid-term due to increased traffic and to counter complacency. The importance of Concentration on the task at hand is likely to remain unchanged in the mid-term. However, Recall from Interruption might play a greater role in successful job performance with increased traffic loads and multiple display-based information sources. As noted in the descriptions of multi-aircraft

operations in the present and in the future, controllers are often called upon to start actions with one aircraft, shift to another, then another, and then return to the first aircraft to complete the cycle. Their work might be characterized as serial interruption; returning to an action "in suspense" is, and will be, important.

Dynamic comprehension, problem solving, and thinking ahead of the traffic situation are at the heart of controller cognition. On one hand, the abilities required to comprehend the traffic situation, solve any problems, and think ahead of the traffic will remain very nearly the same in towers at non-OEP and other airports. On the other hand, understanding the present and future state of surface and airborne traffic at the largest and busiest airports will be a significant challenge to controllers in the mid-term. The demand on Situational Awareness at these airports will be driven by increased traffic, more complex displays, mixed equipage, and implementation of DSTs. However, well designed displays and DSTs will enable controllers to "look ahead" of proposed operations. The DSTs might also summarize information in a more accessible manner in tabular and graphic displays. The net effect will be to reduce Visualization, Dynamic Visual-Spatial, and Summarizing Information by the controller as the bases for control actions in towers at the 30 Core and other large towers.

Solving problems will be more complicated at these large towers in the mid-term if projected traffic increases materialize. Problem Identification will become more important to job performance to detect and evaluate DST errors and faults and their impact on proposed solutions. The need to prioritize actions (Prioritization) will increase with greater and more complex traffic. Rule Application will be embedded in the DST algorithms; hence the need for that aptitude will decrease in the mid-term. The aptitude to reason conditionally about events ("if-then" Reasoning) will still be important to successful job performance. With the implementation of surface DSTs in the mid-term at large airports, the abilities such as one's innate capability for Thinking Ahead might become less important to successful job performance. For example, the Sequencing and Scheduling, Runway Assignment, and Taxi Routing (with Conformance Monitoring) DSTs will do much of the planning. The importance of Planning and Projection to successful job performance might decrease. Change in the importance of Creativity to successful job performance is linked to the likelihood of situations in which existing (in the mid-term) solutions and procedures do not apply or work, and new, creative solutions are needed. Given the stated assumptions of DST reliability, stability, and operational acceptability, Creativity is likely to be less important in the mid-term.

At the same time, the importance of aptitudes grouped under the rubric of cognitive style is likely to, on the whole, increase in the mid-term. Self-awareness and Self-monitoring/Evaluation will continue to be very or extremely important to successful job performance. Information Processing Flexibility is likely to become even more important in the mid-term as controllers switch between and integrate multiple information sources (some not previously available) and evaluate, revise, and devise solutions to the problems at hand. Task Closure/Thoroughness will also increase in importance in the mid-term, most particularly to ensure that an accurate and up-to-date model of the intended aircraft trajectory is maintained. Depending on CHI design, controllers in the mid-term will need to make more computer entries to capture intent and changes in trajectories than at present. This shift to DST-centered interaction is likely to introduce a new attribute requirement in the mid-term cab: "Trust in Automation." What this label means operationally is still being debated (see Parasuraman, Sheridan, & Wickens, 2008). It is not clear to what degree "trust in automation" is experiential and situational versus dispositional. In general, research supports an experiential component to "Trust in Automation:" System characteristics, such as false alarm rate, predict user trust. In turn, experiential trust predicts automation use. However, Merritt and Ilgen (2008) found that individual differences were related to trust. They recommended distinguishing between dispositional and history- or experience-based trust in the automation. The dispositional or trait-like component identified by Merritt and Ilgen (labeled "Dispositional Trust in Automation" in this report) might be seen as an aptitude for selection purposes.

The last "process" group of aptitudes related to ATC was labeled as Personality: Surgency (Figure 7). It is more likely than not that the factors such as Self-confidence, Taking Charge, Flexibility (Stability/Adjustment), and Working Cooperatively will continue to be very or extremely important to successful job performance in any tower cab. With increased traffic at the 35 OEP airports and mid-size hubs, Tolerance for High Intensity Work Situations might become even more important in the mid-term cab.

Turning to the "output" aspects of the heuristic model of Figure 7, it is clear that controllers will interact with systems via CHIs to a greater degree in the mid-term than at present. In today's tower cab environment, there are relatively few "modern" CHIs; "CHI Navigation" is largely irrelevant. The mid-term cab is likely to be dominated by displays and their interfaces. There are two implications for aptitudes. First, Manual Dexterity, in terms of using a keyboard, mouse, touch screen and/or keypad, might be more important than it is now. Second, and perhaps

more importantly, one's ability to navigate a structured CHI, through screens, menus, windows, drop-down lists, target selection, hot spots, etc. ("CHI Navigation") might be more important to successful job performance than at present.

Finally, some aptitudes might become less important with the introduction of increasingly sophisticated DSTs that are reliable and produce solutions that are operationally advantageous. For example, tower controllers might not need to perform quick, rule-of-thumb distance-rate-time estimates with the advent of tower DSTs. However, as noted previously, the profile of aptitudes required at towers without (or late in receiving) these technologies will be the same as today.

Aptitude Testing Gap Analysis

The current ATCS occupational aptitude test battery assesses many, but not all, of the aptitudes likely to be required in the mid-term tower cab, as shown in Table 4. Several of the tests in current use are intended to assess multiple aptitudes, particularly the two dynamic tests (Letter Factory Test and Air Traffic Scenarios Test). Aptitudes assessed in these two multi-factorial, dynamic tests include Situational Awareness, Planning, Thinking Ahead, Prioritization, Visualization, and Projection. A score representing Situational Awareness is computed from applicant performance on the Letter Factory Test. A single score representing both Planning and Thinking Ahead is also computed from the Letter Factory Test. At present, no score is computed on the basis of performance on either dynamic test to assess applicant aptitude for Prioritization. A method for parsing applicant performance on the Air Traffic Scenarios Test was proposed in the mid-1990s (Broach, 1995) but has never been fully implemented or validated. Further research and development on Prioritization, Visualization, and Projection is needed to close the gap between current and future aptitude requirements.

At present, Scanning is assessed explicitly by the Scan test, while Perceptual Speed and Accuracy is assessed by the Dials Test. Both tests are based on a 2D display. Further research is needed to determine if depth perception will be relevant to future operations in the tower, particularly with respect to the Staffed NextGen Tower concept.

Reasoning is assessed by the Analogies test; the relative importance of this ability is not expected to change with NextGen. In contrast, Flexibility (Information Processing) is expected to become more important to job performance in the tower cab of 2018. This aptitude is not assessed in the current version of AT-SAT (see Table 2.10, Ramos, Heil & Manning, 2001). Test development and validation will be required to address this shortfall.

Traits such as Self-awareness, Stability/Adjustment, Task Closure/Thoroughness, and Tolerance for High Intensity Work Situations are assessed presently in a self-report questionnaire. However, the current assessments are vulnerable to applicant impression management tactics. Research on the reliability and validity of alternative assessments is currently underway.

The current test battery has a component related to Concentration, but it does not have an explicit assessment of Sustained Attention. In the mid-term, the issue might not be sustaining attention under high workload (and little automation support). Rather, sustaining attention under low workload (with more automation support) might be more important. Reflecting these conditions (high versus low workload, with little versus more automation support) in an aptitude test will require further construct definition and validation.

Four aptitudes that will increase in importance are not currently assessed in an explicit manner: Active Listening (specifically, auditory attention in the presence of voice, telephone, alarms and ambient noise), Translating Information, Chunking, and Interpreting Information. Tests of Dispositional Trust in Automation and Computer-Human Interface (CHI) Navigation that might be used in selection will need to be identified or developed and then validated for use by the FAA.

There are three corollary research issues that will require further research. First, the relative weights given to existing test scores should be reviewed. Some aptitudes currently assessed will decrease in importance to performance in the tower cab of 2018; the importance of others will remain the same, and some are likely to become more important. The weighting scheme will require modification to address these changes as well as to incorporate new scores. The second research issue relates to the question of "how much" of a given aptitude is required for some threshold of performance. The overall aptitude score is currently computed as the sum of weighted sub-test scores. Mathematically, low scores on one test are offset by higher scores on other tests (depending on the weight given a particular score). Research is needed to assess the benefits and costs of using minimum cut-scores on each measure as part of the overall scoring model. The third research issue reflects the differences in degree, if not kind, in aptitudes required in the towers at the 30 largest airports and in the towers at mid-size and smaller airports. It might be the case that differential weighting schemes and cut-scores by tower size (towers for the 30 largest airports versus other towers) are needed. Empirically demonstrating differential validity by facility level (large versus other tower) will be challenging.

Table 4: Changes in aptitude requirements at 2018 (at 35 OEP & other large airports), rationale, and coverage by AT-SAT, organized into Figure 7 heuristic input-process-output model

Worker Requirement	In 2018	Rationale	AT-SAT[1]
		INPUT	
Active Listening (Auditory Attention)	Same	Voice, telephone, alarms, ambient noise	
Scanning	Increase	DST CHIs + Out-The-Window (OTW)	ATST, LFT, SC
Perceptual Speed and Accuracy	Increase	Multiple visual (DST & DataComm CHIs, OTW) & Audio sources	ATST, LFT, SC, DI
Translating Information	Increase	DST & display symbology	
Chunking	Increase	DST & display symbology	
Interpreting Information	Increase	DST & display symbology	
		PROCESS	
Short-term Memory	Same		
Attention			
Concentration	Same		LFT
Sustained Attention	Increase	Risk of DST-induced complacency, Increased traffic	
Recall from Interruption	Increase	Increased traffic	LFT
Dynamic Comprehension			
Situational Awareness	Increase	DST recommendations, DataComm messaging, CHIs	ATST, LFT
Visualization	Decrease	DST, Displays "look ahead" (particularly with graphic displays)	ATST
Dynamic Visual-Spatial	Same		ATST, LFT
Summarizing Information	Decrease	DST, Displays	
Long-term Memory	Increase	Memorize procedures, DST algorithms (at some level), and user interface actions	
Problem Solving			
Problem Identification	Increase	DST Error, Modes, Faults, Solution evaluation	EQ
Prioritization	Increase	Increased traffic	ATST, LFT
Rule Application	Decrease	DST applies rules	AY
Reasoning	Same		ATST, AY
Thinking Ahead			
Thinking Ahead	Same	"Stay ahead of the problem" even with DST support	ATST, LFT
Planning	Decrease	DST-based planning	ATST, LFT

Table 4 (continued)

Worker Requirement	In 2018	Rationale	AT-SAT[1]
Projection	Decrease	DST, Displays "look ahead" (particularly with graphic displays)	LFT, ATST
Creativity	Uncertain	Depends on assumptions about DST reliability and likelihood of "Black Swan" off-nominal events	
Time Sharing	Increase	Multiple DST & DataComm, Increased traffic	LFT
Cognitive Style			
Self-awareness	Same		EQ
Self-Monitoring/Evaluating	Same		EQ
Flexibility (Information Processing)	Increase	Multiple sources of information, DST Mode changes, Adaptation of DST-generated plans	AY
Task Closure/Thoroughness	Increase	DST & DataComm follow-through (update system to ensure current with ATCS intent)	
*Trust in Automation[2]			
Personality (Surgency)			
Self-Confidence	Same		EQ
Taking Charge	Same		EQ
Tolerance for High-Intensity Work Situations	Increase	Increased traffic	EQ
Flexibility (Stability/Adjustment)	Same		EQ
Working Cooperatively	Same		EQ
		OUTPUT	
Oral Communication	Decrease	DataComm	
*CHI Navigation (Menus, Windows, etc.)		CHI	
*Manual Dexterity (Keyboard, Mouse, Touch screen, Keypad)		CHI	

Notes: [1]AT-SAT: Blank indicates aptitude not assessed in current test configuration; ATST = Air Traffic Scenarios Test; LFT = Letter Factory Test; SC = Scanning; DI = Dials; AY = Analogies; AN = Angles; AM = Applied Math

[2]New worker requirements indicated by asterisk preceding construct label (*Label)

CONCLUSION AND RECOMMENDATIONS

The mid-term NextGen tower cab in 2018, even in the towers for the 30 largest core airports, will be familiar to current controllers. In all likelihood, the tower cab will still be at the airport, and the controllers will view the airfield and operations directly through windows. New and perhaps larger displays will be available to supplement the out-the-window view of the operations on the surface and in the immediate airspace around the large, busy, and complex airports. The functions performed by humans are likely to not change in the mid-term NextGen tower cab, particularly at the less complex mid-size and smaller airports staffed by the FAA. That is, the cab controllers will retain overall responsibility for the safety of operations on the airport movement area. Human controllers will still monitor aircraft and vehicle movement, supplementing the out-the-window view with one or more graphic displays similar to that provided by ASDE-X. Flight strips and scratch pads will be replaced by electronic flight strips arranged in bays according to the phase of operation (pending, departure, arrival, for example). The controllers will interact with those flight strips through a touch screen and perhaps a mouse, though the CHI has yet to be fully specified. Most importantly, automation implemented as DSTs will be an aid to performance of functions such as managing a sequence of departures; the DSTs will not replace controller judgment in the mid-term. Nor does it appear that the DSTs will be enabled to take action "automatically" without controller approval, at least in the mid-term. The DSTs will propose solutions; the cab controllers – particularly in the Ground Control and Local Control positions – will evaluate the automation-generated solutions and then accept, reject, or modify those solutions.

Overall, careful consideration of how work in the tower cab might be performed in the mid-term (about 2018) does not support the wide-spread rhetoric that NextGen automation tools will so transform the work that a radically different profile of fundamental human abilities and traits will be required to enter the ATCS occupation. On one hand, the aptitude profile for the mid-term tower cab is likely to be very similar to that required today for the 5,000+ controllers working at mid-size and smaller airports with FAA towers. This especially applies to busy facilities dominated by general aviation operations such as VNS and RVS. On the other hand, it is likely that there will be a shift in emphasis in aptitudes for controllers at the large, complex core 30 hub airports as new surface DSTs are fielded in the mid-term. Two new CHI-related aptitudes were identified for the mid-term in this analysis. Gaps in current testing in relation to mid-term requirements were also identified. The likely shift in relative importance of some worker requirements in the mid-term suggests reviewing cut-scores and the relative weights given to aptitudes currently assessed.

To address these gaps in current aptitude testing, the following recommendations are made in the context of mid-term tower cab air traffic control.

First, adapt or develop and then validate tests for Dispositional Trust in Automation; CHI Navigation; and Manual Dexterity. These aptitudes are not currently assessed in pre-employment aptitude testing but will be important to job performance under NextGen.

Second, adapt or develop and then validate tests for the following aptitudes: Translating Information; Chunking; Interpreting Information; Sustained Attention; and Long-term Memory; and Time-sharing. These aptitudes were identified as important in the baseline job analysis. They are likely to become more important to job performance in the mid-term tower cab than at present, particularly with implementation of surface-oriented DSTs under the NextGen umbrella. These aptitudes are not currently assessed in pre-employment aptitude testing.

Third, derive scores from the multi-factorial tests, if possible, to represent the aptitudes Prioritization and Time-sharing. These aptitudes are likely to become even more important in the mid-term tower than they are now because of both NextGen and increased traffic. Alternatively, adapt or develop tests of these aptitudes. Validate the derived, adapted, or newly developed tests for these aptitudes against mid-term job performance measures for tower cab controllers.

Fourth, conduct multi-trait, multi-method analyses of Scanning of different sources of visual information such as a true 3-D out-the-window view versus 2-D representation of that view and 2-D radar display. Determine if different tests are required.

Fifth, review the relative weights for aptitudes assessed in the current occupational aptitude test battery in relation to their increased importance to the mid-term cab environment with surface DSTs. In other words, reflect the shift in emphasis or degree on the various aptitudes relevant to job performance in the mid-term towers of large airports in the weights assigned to scores representing relevant aptitudes. This recommendation includes determination of cut-scores to reflect minimum requirements, if justified.

Sixth, investigate alternative assessments of Sustained Attention and Concentration that do not rely upon transparent, self-report questionnaires of typical behavior.

Finally, each of these studies should be conducted in accordance with accepted guidelines, standards, principles, and practices for the development and validation of personnel selection tests. Specific attention and resources must be given to the development of meaningful, reliable, and valid measures of controller job performance in the tower cab of 2018 against which to validate future-oriented tests.

FOOTNOTES

[1]ATCS will be used throughout, as it is more familiar and widely used, rather than the idiosyncratic ANSP, except in direct quotes.

[2]Runways are labeled by their heading and, where there are multiple runways on the same compass heading, by the relative position as it appears to the pilot. For example, at DFW, the three north-south runways on the east side are on a compass heading of 170 (to the south) and 350 (to the north). On approach (landing) from the north, the inboard runway closest to the terminal would be labeled "17L," the middle runway would be labeled "17C," and the farthest east runway would be labeled "17R." The east-side diagonal, running on a 130 compass heading (and its reciprocal, 310) is labeled "13L," while the diagonal on the west side of DFW is labeled "13R."

[3]Excluding Flight Service, which was contracted out in 2005 to Lockheed-Martin, Inc.

[4]No specific model or architecture of cognition is implied by Figure 7. It is meant simply to be a means for organizing the description of the 1995 Nickels et al. job/task analysis.

[5]When referring to a specific DST, the function is capitalized and in italics in the text: *Sequencing and Scheduling* DST. The generic function accomplished by the specific DST is not capitalized or italicized: Algorithms for sequencing and scheduling a bank of outbound flights must be developed.

[6]A non-supervisory ATCS will temporarily assume limited, operational supervisory responsibilities as a Controller-In-Charge (CIC) under certain conditions; for example, if the on-duty supervisor is "off the floor" attending a meeting or other reason.

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APPENDIX A

Worker requirements identified by Nickels et al. (1995), sorted in descending order of mean (average) importance to successful controller performance

Worker Requirement	Description/Definition	Mean	SD
Tolerance for High-Intensity Work Situations	The ability to perform effectively and think clearly during heavy work flow.	4.60	0.62
Oral Communication	The ability to speak clearly and concisely to individuals so they understand what is being communicated. Projecting a confident tone of voice is an important component of this ability.	4.56	0.63
Active Listening	The ability to hear and comprehend spoken information. This ability requires an individual to recognize or pick out pertinent auditory information.	4.53	0.66
Prioritization	The ability to identify the activities that are most critical and require immediate attention. This involves a constant evaluation of new information followed by re-prioritization of job activities.	4.53	0.70
Concentration	The ability to focus on job activities amid distractions for short periods of time.	4.50	0.70
Planning	The ability to determine the appropriate course(s) of action to take in any given situation.	4.45	0.69
Dynamic Visual-Spatial	The ability to deal with dynamic visual movement.	4.40	0.71
Flexibility (Information Processing)	The ability to find new meanings for stimuli, to combine stimulus attributes to come up with new and different solution protocols, and to employ flexible ways of relating new information to stored knowledge.	4.37	0.80
Thinking Ahead	The ability to anticipate or recognize problems before they occur and to develop plans to avoid problems. This includes thinking about what might happen.	4.35	0.81
Scanning	The ability to quickly and accurately search for information on a computer screen, radar scope, or computer print-out.	4.33	0.79
Situational Awareness	Being cognizant of all information within a four dimensional space (i.e., Separation Standards plus time). This involves the ability to "understand" the airspace as an integrated whole (e.g., getting the picture).	4.33	0.86
Reasoning	The ability to apply available information in order to make decisions, draw conclusions, or identify alternative solutions.	4.31	0.74
Short-term Memory	The ability to remember pertinent information within a brief period of time (less than one minute). Examples of information include call signs and keywords.	4.30	0.80
Taking Charge	The ability to take control of a situation--to reach out and take correct action.	4.30	0.73
Visualization	The ability to translate material into a visual representation of what is currently occurring.	4.26	0.85
Projection	The ability to translate material into a visual representation of what will occur in the future.	4.26	0.84
Time Sharing	The ability to perform two or more job activities at the same time.	4.26	0.78
Rule Application	The ability to apply learned rules to the real work situation.	4.25	0.79

Worker Requirement	Description/Definition	Mean	SD
Creativity	The ability to identify new or novel solutions to potential problems when existing or established solutions no longer apply.	4.23	0.80
Problem Identification	The ability to identify a potential or existing problem and to identify the variables used in solving the problem.	4.23	0.83
Flexibility (Stability/Adjustment)	The ability to adjust or adapt to changing situations or conditions.	4.22	0.77
Perceptual Speed and Accuracy	The ability to perceive visual information quickly and accurately and to perform simple processing tasks with it (e.g., comparison).	4.13	0.83
Long-term Memory	The ability to remember pertinent information much later in time (longer than 10 minutes). Examples of information include maps and separation procedures.	4.11	0.92
Self-awareness	An internal awareness of your actions and attitudes. This includes knowing your limitations.	4.11	0.78
Working Cooperatively	The willingness to work with others to achieve a common goal. This includes a willingness to voluntarily assist another controller if the situation warrants.	4.10	0.81
Sustained Attention	The ability to stay focused on a task(s) for long periods of time (over 60 minutes).	4.07	0.94
Summarizing Information	The ability to summarize and consolidate information most relevant to the situation.	4.06	0.83
Self-Monitoring/Evaluating	The ability and willingness to check your own work performance, evaluate the effectiveness of your decisions, and alter your performance if necessary.	4.04	0.84
Self-Confidence	A belief that you are the person for the job and knowing that your processes and decisions are correct.	4.02	0.78
Internal Locus of Control	Believes that individuals have influence over the outcome of an event; takes responsibility for outcomes.	3.96	0.88
Task Closure/Thoroughness	The ability to continue an activity to completion through the coordination and inspection of work.	3.96	0.85
Reading	The ability to read and understand written information (e.g., ATCS documents, manuals).	3.95	0.89
Recall from Interruption	The ability to recall a deferred or interrupted action when priorities permit, and to be able to resume the action appropriately (Ammerman, 1983).	3.92	0.90
Decisiveness	The ability to make effective decisions in a timely manner.	3.92	0.90
Verbal Reasoning	Ability to perceive and understand principles governing the use of verbal concepts and symbols.	3.89	0.86
Composure	The ability to think clearly in stressful situations.	3.88	0.92
Translating Information	The ability to translate symbols/symbolic abbreviations into meaningful information.	3.88	0.98
Interpersonal Tolerance	The ability to accommodate or deal with differences in personalities, criticisms, and interpersonal conflicts in the work environment.	3.83	0.92
Movement Detection	The ability to detect physical movement of objects and to judge their direction.	3.80	1.03
Execution	The ability to take timely action in order to avoid problems and to solve existing problems.	3.80	1.02
Attention to Detail	The ability to recognize and attend to the details of the job that others might overlook.	3.80	0.85
Professionalism	The ability to establish respect and confidence in your abilities among other controllers.	3.79	0.87

Worker Requirement	Description/Definition	Mean	SD
Visuospatial Reasoning	Ability to perceive and understand principles governing relationships among several figures.	3.78	0.97
Chunking	Ability to organize stimuli into meaningful groups or units.	3.78	1.00
Self-esteem	Having a positive opinion/image of oneself.	3.77	0.88
Behavioral Consistency	The ability to behave consistently at work (e.g., dealing with coworkers in a consistent manner; consistently using the correct phraseology).	3.76	0.85
Interpreting Information	The ability to put information into meaningful terms. It is the ability to recognize the implications of a statement or condition (e.g., cold front).	3.68	0.86
Translation of Uncertainty	The ability to assign a subjective probability regarding the likelihood of an event occurring; The ability to use probabilities to identify optimal courses of action (CTA, 1988)	3.67	1.01
Commitment to the Job	The desire to be an ATCS and work hard to be successful.	3.53	0.92
Motivation	The desire to motivate oneself through challenges on the job and to progress to a higher level of skill.	3.47	0.93
Written Communication	The ability to write legibly and accurately (e.g., strip markings).	3.40	0.96
Intermediate-term Memory	The ability to remember pertinent information over a 1-10 minute period.	3.32	1.13
3-D Mental Rotation	The ability to identify a three-dimensional object when seen at different angular orientations either within the picture plane or about the axis in depth.	3.24	1.20
2-D Mental Rotation	The ability to identify a two-dimensional figure when seen at different angular orientations.	3.20	1.12
Realistic Orientation	Prefers dealing with activities which have tangible and measurable consequences; enjoys activities which require skill; is reinforced by accomplishing realistic tasks.	3.19	1.02
Mechanical Reasoning	Ability to perceive and understand the relationship of physical forces and mechanical elements in a prescribed situation.	3.15	1.00
Mathematical Reasoning	Ability to perceive and understand principles governing the use of quantitative concepts and symbols.	3.08	1.01
Numeric Ability (Add/Subtract)	The ability to quickly and accurately perform basic math operations (primarily addition and subtraction).	2.91	1.02
Angles	This is the ability to apply the principles of geometry to angles and computations involving angles. The ability involves both the speed and accuracy of computation.	2.79	1.13
Numeric Ability (Multiply/Divide)	The ability to quickly and accurately perform basic math operations (primarily multiplication and division).	2.63	1.04